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Editorial

Traditionally all abstracts of contributions submitted to the 23rd General Assembly are included free of charge in the *Annales Geophysicae Supplement* once they were accepted by the appropriate convener(s) and once they were received in time, in the standard format and of sufficient quality for reproduction. Abstracts submitted for symposia included in two different parts of the Supplement issue are included (twice) in both parts, respectively.

Like in previous years, not all contributions included will actually be presented. Because of the lack of financial support, several young scientists as well as colleagues from the central and east-European countries will not be able to participate in the meeting, although the Society has continued its support schemes, such as the Young Scientists' Travel Award and the East European Support Award. In this way there are more abstracts included in the *Abstract Book* than contributions compiled in the *Programme Book*. Therefore, in order to simplify the ordering of abstracts within an event, we have adopted the alphabetical order with respect to the surname of the first author rather than the order of presentation in the *Abstract Book*.

With almost 5.800 contributions received, this Supplement of *Annales Geophysicae* has become an important open forum for fast distribution of results of geophysical research on a pan-European, international level, helping, at the same time, to promote the contact between all geophysicists in Europe. Please, support the fostering of cooperation and contact your colleagues also if not personally present this time. For this reason, the authors have also included a contact e-mail or fax number in their abstract for faster correspondence.

On behalf of the Society I am very pleased to welcome you to Nice on the occasion of the 23rd General Assembly of the European Geophysical Society. May your participation in this meeting be successful and scientifically rewarding.

A.K. Richter
Executive Secretary

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NP1 Scaling, multifractals and nonlinear variability in geophysics

Convener: Schertzer, D.
Co-Convener: Lovejoy, S.M.

01 Scaling, multifractals and nonlinearity in Solid Earth (joint with SE)

Convener: Schmittbuhl, J.
Co-Conveners: Bak, P.; Turcotte, D.L.

EXPERIMENTAL ANALYSIS OF FRACTURE RUGOSITY IN GRANULAR AND COMPACT ROCKS

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Self-affine properties of the rugosity geometry for fractured granite and sandstone samples have been compared using two experimental techniques. Mechanical profilometry measurements on granite confirm that Hurst's exponent H is close to 0.8 over the full experimental range ($50\mu m - 10cm$) as reported previously. For sandstone, the rugosity spectrum is independent on the fracturation velocity but follows a power law only above a cutoff length scale of the order of the grain size. Moreover, the value of H in the self-affine part is distinctly smaller (0.45 ± 0.05) than for granite. Numerical simulations modelling the faceted shape of the sand grains reproduce the cutoff effect while keeping the value of H unchanged. The different H values in granite and sandstone may reflect the extragranular nature of fracture in the latter case. These results are compared to measurements of the lengths of shadows on such surfaces illuminated under grazing incidence. A power law distribution of the lengths with and exponent -1-H is expected up to a cutoff value depending on the amplitude of the rugosity and on the incidence angle. Diffusion and reflexion phenomena give varying light intensities in shadows requiring the use of a local thresholding algorithm. Images of large aspect ratio (8000 x 600) are used to improve the measurement statistics on the distribution. Results obtained with this technique are in fair agreement with mechanical profilometry measurements.

BURRIDGE-KNOPOFF MODEL AND SELF-SIMILARITY

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The seismic processes are well known to be self-similar in both spatial and temporal behavior. At the same time, the Burridge-Knopoff (BK) model of earthquake fault dynamics, one of the basic models of theoretical seismicity, does not posses self-similarity. In this article an extension of BK model, which directly accounts for the self-similarity of earth crust elastic properties by introducing nonlinear terms for inter-block springs of BK model, is presented. The phase space analysis of the model have shown it to behave like a system of coupled randomly kicked oscillators. The nonlinear stiffness terms cause the synchronization of collective motion and produce stronger seismic events.

BEHAVIOR OF THE DIVERSITY OF FRAGMENTS IN PLATE BREAKING

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Fragmentation plays an important role in many geophysical phenomena e. g. in tectonics, weathering, and natural and artificial explosions. In the present work, we study the fragmentation of brittle solids (cement and cement-gypsum plates of square shape and different sizes) under application of periodic impulsive forces, emphasizing the time dependence of the diversity of fragments, D(t), which is defined as $D(t) = \Sigma_s \Theta(n(s,t))$, where $\Theta(x) = 1$, if $x > 0$, and 0 otherwise. We have observed from the experiments several relationships between D(t), the total number of fragments, N(t), and the size of the plates. Extensive computer simulations of the processes using highperformance workstations were made and agree with the experimental data. Among other relations we have found (i) a robust scaling relation between the maxima of N(t) and D(t), i.e. $N_{max} \sim D_{max}^2$, (ii) the number of fragments of size s at the time of maximum diversity, n(s), scales as $n(s) \sim s^{-1.8 \pm 0.1}$, in close agreement with a recent study of self-organized criticality in fragmenting.

VARIATIONS OF PREDICTABILITY OF STRONG EVENTS IN A HIERARCHICAL MODEL OF SEISMICITY

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Predictability of strong events in a hierarchical model representing general features of seismicity is considered. A simple algorithm of prediction of strong events based on variations of the average magnitude is applied in order to investigate possible variations of the predictability.
Two kinds of variations of the predictability are obtained for the given algorithm. The predictability strongly depends on parameters of the model: predictable and unpredictable synthetic catalogs exist. Strong temporal variations of quality of prediction is obtained for the fixed algorithm and parameters of modeling. Temporal variations are also observed for the optimal threshold of the prediction. Observed variations may explain variations in the predictability of strong earthquakes in different seismic regions and the difference between the retrospective and forward prediction.

A FRACTAL APPROACH TO THE STRUCTURAL ANALYSIS OF MELANGES

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Melanges exhibit a pronounced non-coherent deformation and the recognition of this has traditionally let to the application of classical methods of structural geology developed in the ductile strain regime. Despite their chaotic appearance, melanges should show some degree of internal organization that traditional methods often do not take in right perspective. The wide variety of genetic mechanisms responsible of melanges formation complicates further on this picture. So far several studies have been showing that exist some kind of geometrical self-similarity relationship among different kind of melanges. The investigated relationships are mainly connected with the spatial pattern of blocks in matrix distribution and the frequency distribution of blocks themselves. Based on these fractal properties, our attempt concentrates on an alternative approach to the study and description of melanges. The studied disrupted sequence lies on western coast of Tuscany, near the city of Livorno. From a stratigraphic point of view it belongs to the "Palombini Shales" formation of Cretaceous age. It consists of a deformed series of bedded siltstones and limestones with interbedded shales that locally can become predominant over the competent lithotypes. Much of the sequence is coherent but disrupted units are present where the shales prevail and in association to a major shear zone. The deformation features recognized here are both symmetrical and asymmetrical blocks, isolated hinges often refolded, pinch-and-swell, while the matrix is characterized by scaly fabric, C-S-structures and locally by some crenulation cleavage. From a geometrical point of view a melange can be considered as a binary system in which the blocks are discriminated by the matrix. The fractal model that better fits this system is the Sierpinski Carpet that can be theoretically built starting from a square generator unit, dividing each side of it in three equal portions and subtracting the central ninth each time for an infinite number of steps. Obviously, in natural systems, the best fitting model is a random version of the theoretical Sierpinski fractal, characterized by different fractal parameters that give us a sort of geometrical "signature" of melanges. The application of this models to the studied outcrops can lead to a better description of the spatial distribution of the different blocks helping in the 3D strain analysis. Besides, because of the promptness of that fractal method, it can also be used as a preliminary approach in alternative to classical, time-consuming methods.

DETECTING SCALING LAWS AND NON-LINEAR DINAMICS IN GEOELECTRICAL SIGNALS: IMPLICATIONS WITH EARTHQUAKE PREDICTION.

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In this work precursory geoelectrical time series measured in a seismic area of Southern Italy are examined, both in frequency and in time domains. The Higuchi fractal method to estimate the spectral power-law index has been applied, because the correlation between the length curve L(t) and the time interval t is better than the correlation between the power spectrum P(f) and the frequency f. In the time domain we analyzed the predictability of geoelectrical time series by using two forecasting autoregressive approaches: the global autoregressive approximation and the local autoregressive approximation. The first views the data as a realization of a linear stochastic process, whereas the second one considers the data as a realization of a non-linear deterministic process. The comparison of the predictive skill of the two techniques is a powerful test to discriminate low-dimensional chaos by random dynamics. Our findings are that in the geoelectrical precursory signals the stochastic nature is predominant. Then, all the possible implications with the short-term earthquake prediction are discussed.

SIZE-FREQUENCY DISTRIBUTION OF EARTHQUAKES IN HIERARCHICALLY ORGANIZED LOAD-TRANSFER MODELS

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Large hierarchically organized sets of elements (simulating asperities in a fault) are loaded to the point of complete failure. The fracture thresholds of individual elements are stochastically distributed, and the hierarchical structure for load-transfer is of the fractal-tree type. During the breakdown process there occur bursts (earthquakes) of several elements breaking simultaneously at a given load. Using Monte Carlo simulations we compute the frequency of bursts versus their size. This shows a gross power-law behaviour superimposed by a wavy pattern closely related to the coordination number of the fractal tree used for the load-transfer structure.

PRINCIPLE OF FASTEST RESPONSE IN GEOPHYSICS, HYDRODYNAMICS, ETC.

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The principle says: if we know the generation rate $q = dA/dt$ of a certain value A, then $A \approx q\tau$, where τ is the shortest time the system in consideration has. In nature we often know q, such as the solar constant, or the geothermal heat flux for dynamics of atmosphere and ocean, or geodynamics. In hydrodynamics the comparison of times due to various terms in the Navier-Stokes equation gives usual similarity criteria of Reynolds, Rossby, Mach, etc. The principle reproduces readily all major results of hydrodynamics of forced flows in tubes, gravity field, turbulence in 3D and 2D, convection with and without rotation, mean wind on terrestrial planets, etc. New results are: frequency-intensity spectra for tropical cyclones, earthquakes, cosmic rays. Other applications of the principle may be envisioned. Relationship of the principle to the similarity theory, fractals will be discussed.

STADY OF NONLINEAR ELASTIC PROPERTIES OF ROCKS BY DYNAMIC CHARACTERISTICS OF TECHNOGENEOUS HARMONICS

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Seismic noise recordings from seismic stations "Obninsk", "Kislovodsk", "Arti" (Russia), and "Dobrushka" (Czech Republic) are analysed. All recordings contain industrial harmonics, such as 1 Hz, 1.25 Hz, 2 Hz, 2.5 Hz, etc. Nonlinear elastic properties of rocks in the vicinities of seismic stations can be estimated by coefficients of modulation of industrial harmonics by intense low-frequency processes, as storm microseisms and tides. To estimate nonlinear elastic properties of media, so-called "natural widths" of spectral lines of industrial harmonics and spectra of their amplitude and phase variations are studied. The results are compared with the results of numerical modeling. Conclusions are made about parameters of elastic nonlinearity of rocks in the vicinities of the seismic stations. To test these estimates, bispectral characteristics of seismic noise are calculated for the studied regions, and evaluation of parameters of elastic nonlinearity is made by bispectral amplitudes of seismic noise.

DETERMINISM AND PRECURSORS IN EARTHQUAKE INTERVALS

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It is now widely believed that earthquakes constitute a highly nonlinear, probably chaotic process. In practical earthquake prediction, earthquake-related parameters are monitored in the field to detect so-called anomalies with precursory qualities by watching for 'peaks'. The same is true for analysis of spatial seismicity patterns whose temporal properties are also summarised in a time series. In the light of chaotic processes, however, it becomes clear that this simple approach does not reflect the necessarily higher degree of freedom of the underlying process. To be able to monitor properties of a chaotic system, analysis must instead be carried out in phase space. In the case of low-dimensional deterministic chaos one expects a so-called strange attractor in phase space whose properties should ideally be monitored for precursory behaviour. Unfortunately, nonlinear analysis of a great variety of real world signals has shown that the signals almost always posess too high a degree of freedom for numerical treatment, due to noise or the signals true inherent complexity. In this work, a series of earthquake intervals was constructed directly from an earthquake catalogue and a low dimensional deterministic structure was detected. Determinism of the attractor was confirmed by analysing phase randomised data. Furthermore, a Poisson distribution could not produce similar results. A first application of 'phase space monitoring' is shown and seems promising.

A CREEP-SLIP MODEL OF EARTHQUAKE FAULTS: ANALYTICAL AND NUMERICAL RESULTS

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The classical spring-block model by Burridge and Knopoff (BK) is generalized in a way to account for the irreversible deformation (creep) of the fault interface in addition to rigid sliding displacements. By this generalization the driving forces are allowed to relax, and a rate and state-dependent friction with velocity softening is introduced. The model exhibits a new kind of short-wavelength instability which is associated to microfissuration during aseismic creep and by means of which parts of the fault self-organize to the critical state defined by the onset of velocity softening. The model is discussed in relation to the BK model (where this type of instability is absent) and compared to threshold models exhibiting self-organized criticality. Numerical results show intermittency of the seismic cycle and give power-law scaling of the event-size distributions. Implications of the model with respect to the predictabilty of earthquakes are discussed.

FRACTAL CHARACTER OF THE EARTH'S EVOLUTION

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The fractal properties and scaling of the Earth's magnetic field reversals are the peculiar characteristic of the Earth's evolution. The suggested model is based on that the thickness of the Earth's outer core was gradually increasing during the evolution; the formed convective cells with increasing the core thickness changed so that their number decreased when the cell sizes increased; the Earth's magnetic field polarity changed when the regime of convection changed; when the convection was steady, the magnetic field was stable; the convective cells arising in the core has the similar fractal structure and they belong to the same class of universality. The ordered multitude, characterizing the period durations of the steady convection and the period of its structure change and possessing the scale properties, is estimated with the multitude of the periods of the Earth's magnetic field reversals. Their community suggests that this model is equivalent to the nature of changing the polarity of the Earth's magnetic field.

A FRACTAL PIPE MODEL FOR VOLCANISM

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Volcanoes within volcanic arcs and fields are clustered in space and their eruptions are clustered in time. We utilize the pair correlation function, the number of pairs of volcanoes as a function of the radius separating the pairs, normalized by the number expected from a Poisson process, to quantify the clustering of volcanoes in several volcanic arcs and vent fields. Scale-invariant clustering is observed. The pair correlation function in time is used to identify scale-invariant clustering of eruptions in time. We also analyze spatial and temporal clustering in volcanic rocks with the Radiometric Databank of 11,986 dated volcanic rocks in the North American Cordillera and find scale-invariant clustering with statistics identical to those of distributed seismicity. In addition, the frequency-size distribution of eruption volume is a power law analogous to the Gutenburg-Richter distribution for earthquakes with a 'b' value of 1. In an attempt to explain these observations, we first consider a model for the spatial clustering of volcanoes and the size distribution of magma chambers in terms of a simple model of an upwelling instability of magma through the upper mantle and crust. This model geometry is then used in conjuction with a model for the flow of magma through upwelling channels that terminate at magma chambers with a pressure-dependent time-to-failure probability of eruption. The frequency-size distribution of eruptions and the clustering of volcanoes in space and eruptions in time are identical to those observed.

THE SELF-ORGANIZING CRITICALITY AS THE REASON OF THE GEOMAGNETIC FIELD REVERSAL

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According to the "hot' Earth's model, the region of the phase change on the inner core boundary can be presented in the form of the large number of interacting elements in which the phase change "condensation-evaporation" takes place. Such system can not in principle to achieve the thermodynamic equilibrium. It evolves to the critical state in which any small event causes the chain reaction; the system changes the direction of the phase change, for example, the advantage of condensation changes on the advantage of evaporation. In doing so, the change of the electric field polarity takes place arising on the phase change and, as result, the polarity of magnetic field changes.

MULTIFRACTAL TOPOGRAPHY AND ITS BI-DIRECTIONAL REFLECTION FIELD

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The analysis of DEM's in recent years has led to considerable evidence that many topographic and bathymmetric fields display multiscaling characteristics over scales ranging from the size of the Earth down to at least 90m. Remotely sensed surface reflectivity fields also show multifractal statistics with roughly the same basic multifractal parameters; apparently only the non-conservative parameter H is significantly different.

Using simple theoretical models and numerical simulations we study the relationship between the scale-by-scale statistical properties of a given radiance field and those of the underlying topography profile. The statistics of the calculated radiance field are then compared with those of the known topography field, allowing direct comparison of the two fields' scaling parameters including those determining the anisotropy and morphology.

THE MAGNETIC FIELD, SCALING STRATIFICATION AND THE MAGNETIZATION SPHERO-SCALE

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The standard model of the structure of the earth is that that the horizontal and vertical structures are qualitatively quite distinct; the latter generally being refered to as "strata". Many geophysical fields have been shown to be scaling in both horizontal and vertical directions; this raises the possibility of a unified horizontal/vertical description and model based on generalized scale invariance (GSI). In certain cases such as the susceptibility (and by inference magnetization), it has been empirically suspected (Pilkington and Todeschuck 1993) that the spectral scaling exponents are different in the two directions. Stratification is very pronounced at small scales, but at larger scales the stratification dimishes. Eventually one power law exceeds the other (at a roughly isotropic scale called the "sphero-scale"), while at still larger scales, the stratification reverses direction (e.g. mountains have "roots").

We use the well-known statistical relationship between surface magnetic anomalies and the magnetization, showing that if the latter is scaling but anisotropic, the magnetic field will have a break in the scaling at the sphero-scale with different high and low frequency exponents that are related to the "elliptical dimension" (D_{el}) of the magnetization. Using a dozen aeromagnetic and susceptibility surveys and borehole data we show that $D_{el} \approx 7/3$ (a value 3 would indicate an unstratified earth, a value 2, totally stratified), and (as expected) a variable sphero scale (in the range $\approx$8 to $\approx$50km).

ANOMALOUS SCALING OF FRACTURE SURFACES

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We argue that fracture surfaces exhibit *anomalous* dynamic scaling properties akin to what occurs in some models of kinetic roughening. We determine the complete scaling behavior of the growth of local topography fluctuations of a brittle fracture in a granite block from experimental data. We obtain a global roughness exponent $\chi = 1.2$ which differs from the local one, $\chi_{loc} = 0.79$. Implications on fracture physics are discussed.

SELF-ORGANIZED CRITICALITY AS A RESULT OF HETEROGENUITY OF MEDIA: MIXED HIERARCHICAL MODEL

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We are interesting in investigation of general features and appearing conditions of critical behavior in self-similar systems. Two kinds of critical behavior are separated. An unstable critical behavior exists in isolated points, it is usually connected with a phase transition. A stable critical behavior such as the self-organized criticality exists in a nondegenerate area of system parameters. We consider a simple model where both kinds of criticality are achived.
A hierarchical model of defects representing a mixture of the simplest transition operators is suggested. Four kinds of system behavior are realized: stability, catastrophe, phase transition from stability to catastrophe and a stable critical behavior (SOC). The condition to obtain a stable critical behavior is determined in terms of parameters of the mixture. It is shown that the self-organized criticality expresses heterogeneous properties of the media.
Different precursory patterns for strong earthquakes reflecting concrete type of system behavior are described.

HETEROSCEDASTICITY, HURST, AND SURROGATE DATA: PERSISTENCE WITHOUT PREDICTABILITY

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The analysis of a variety of nonlinear geophysical data sets often reveals "long range dependence" which is in turn taken as an indication of enhanced predictability. It is illustrated that "long range dependence" need not imply any useful increase in predictability. This is the case, for instance, with seasonal heteroscedasticity; surrogate data methods for identifying this type of technically "nonlinear" behaviour are provided. Surrogate data consists of artificially generated data from a known process constructed so as to mimic some properties of an observed data set. Its value lies in identifying the lack of significance of a particular data analysis, when the same analysis of a "similar looking" data from the (known) surrogate process yields an result which is (known to be) incorrect. Of course, even if the observed data set can be distinguished from the surrogate data, it might be different for the wrong reason: if the wrong properties of an observed data set were mimicked, then the particular analysis may still be insignificant. Several examples are provided.

LOG PERIODICITY IN THE FOREST-FIRE MODEL

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The forest-fire model is one of three classic examples of models exhibiting self-organized critical behavior; the other two are the sandpile and slider-block models. Log-periodic behavior is fractal behavior with a complex fractal dimension. In the simplest form of the forest-fire model, a square grid of sites is considered. At each time step a site is randomly chosen, either a tree is planted on the site (if it is unoccupied) or a match is dropped on the site. If a match is dropped on a site with a tree, that tree and all adjacent trees burn. The sparking frequency f_0 specifies the number of trees planted (or attempts to plant) before a match is dropped. If f_0 = 1/100, a match is dropped after each 99 time steps. For very small firing frequencies (*i.e.*, 1/10,000 for a 128 x 128 grid) the frequency-size distribution of forest fires cluster at well defined peaks. These peaks approach the size of the grid and satisfy a log-periodic relation. This behavior can be explained in a straight-forward manner. The exponential growth of the forest density combined with a periodic triggering mechanism leads naturally to log periodicity. It is interesting to speculate whether observations of log-periodic behavior in natural phenomena such as earthquakes can also be explained in this way.

A SCALING LAW BETWEEN AN ELECTRIC PRESEISMIC ANOMALY AND THE MAGNITUDE OF THE ASSOCIATED EARTHQUAKE.

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Experimental results suggest that the electric earthquake precursors (EEP) emitted from various regions and recorded in a given field station have maximum electric field value E which is scaled to the magnitude M of the earthquake, by the expression: $\log E = \alpha M + b_i$ (1) where α is a positive slope factor lies between 0.3 and 0.4 and b_i is connected with peculiarities of the observational site. Recently a model based on the motion of charged dislocation (MCD model) has presented in order to describe the generation of EEP. It has concluded that in order to observe an EEP distributed emitting cells are required. In the present work the emitters simulated for simplicity by polarized spheres distributed in the earthquake preparation volume. Without the assumption of any underling generation mechanism, an induced polarization $P(t)=P_o\, u(t)$, u(t) is the step function, appears in the volume of the sphere. Since P varies with time the sphere behaves as a source of electric and magnetic field. Introducing the hypothesis that the number of emitting spheres N is scaling with their radius R as $N \propto 1/R^D$, we lead to an expression similar to (1) where $\alpha=(3-D)/2$. The experiment indicates that D lies between 2.2 and 2.6 leading to α values in the range 0.2-0.4, in comparison with the observed ones. The latter agreement suggests that the scaling law (1) is a result of the geometric distribution of the emitters in the earthquake preparation zone.

A CHARACTERIZATION OF NONSTATIONARY MULTIFRACTAL PROCESSES

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Multifractals are ordinary processes X(t) or generalized processes X[h(t)] that satisfy certain stochastic scaling conditions. For example, a multifractal X(t) satisfies $X(t) =^d r^{-H} A_r X(rt)$ for some deterministic H and some random A_r, with $E[A_r] = 1$, $r \geq 1$ or $r \leq 1$, and t in a certain range. The above scaling condition is of a global nature. In addition, the increments of X(t) may scale locally, in the sense that $X(t+\tau)-X(t) =^d r^{-H'} A_r'[X(t+r\tau)-X(t)]$ for some deterministic H' and stochastic A_r', r as above, and any given t and τ. In the special case when $A_r = 1$ deterministic, X(t) is self-similar. Self-similar processes with stationary increments have identical local and global scaling, with $H = H'$ and $A_r = A_r' = 1$. Analogous global and local scaling properties apply to generalized processes X[h(t)]. We show how processes X(t) and X[h(t)] with various local and global, self-similar or multifractal, scaling properties are related to stationary processes and to processes with stationary increments and how such constructions determine the scaling parameters {H, A_r, H', A_r'}. These characterizations are extensions of a classic result by Lamperti (1962) for globally self-similar processes. An example of ordinary nonstationary multifractal is the model of annual maximum stream flows by Gupta, Mesa and Dawdy (1994), which is globally multifractal with A_r either lognormal or log-Levy. An example of generalized multifractal is the river profile model of Veneziano et al. (1998; this conference), which is globally self-similar ($H = 1$ and $A_r = 1$) and locally multifractal ($H' = 1$ and A_r' log-Levy or the product of a Bernoulli and a lognormal variable).

3-D ORE FRACTALS AND STRANGE ATTRACTORS IN THE TIME SERIES OF THE PRECAMBRIAN BANDED IRON FORMATIONS (BIF).

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An analysis of 100 BIF's magnetic distributions using Takens method showed that spatial variations of magnetite are an exhibition of the deterministic time history of the ore systems. It is established that inclinations of the D=f(d) plots defining a fractal dimension of attractors D=2.05-2.3. This means that magnetite distribution in the ore bodies after folding, metamorphism of BIFs, etc., is controlled and can be set by an interaction of a small number of variables.
Investigations of fractal geological objects (most of them are 3D bodies) as a rule are based on their 1D - 2D sections, or some indirect data (as in seismology). Such investigations, however, do not provide a strong basis for calculation of fractal dimensions.Unique geological and geophysical data of the Kirovogorskoye BIF deposit structures give a possibility to determine 3D fractal dimension of the BIF bodies (D=2.14).
Digital experiments in modelling of re-distribution of components, according to the model system of 8 variables (Si- Fe^{2+}-Fe^{3+}-Ca-Mg-Al-K-Na) show that there is a possibility that structures analogous to BIF bodies could be formed. This testifies that fractal structures of the Kola BIF's are not a random coincidence, but an evidence of functioning of a metamorphic-self-organization system.

NP1 Scaling, multifractals and nonlinear variability in geophysics

Convener: Schertzer, D.
Co-Convener: Lovejoy, S.M.

02 Scaling, multifractals and nonlinearity in hydrology (joint with HS)

Convener: Onof, C.
Co-Conveners: Olsson, J.; Veneziano, D.

MULTISCALING PROPERTIES OF THE THREE DIMENSIONAL SPATIAL DISTRIBUTIONS OF RAIN AND SNOW IN 10 M^3

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High space/time resolution radar rain data reveal multiscaling behaviour down to the resolution scale of a radar pulse volume. If this behaviour continues at sub-pulse volume scales, it will lead to large systematic biases in radar estimates of rain. However, a smaller resolution measuring device has to be used to directly test the small scale behaviour of the spatial distribution of hydrometeors. Stereo photography is used to detect up to 10^5 rain drops or snow flakes in a volume ≈ 10 m^3. The hydrometeors are lighted by two powerful xenon flashes (50 µs, 2000J). Three motorized Hasselblad cameras and stereoscopic reconstruction algorithms provide accurate estimates of their size and position. Multifractal analyses relating to the field of liquid water content (for rain drops) and equivalent liquid water content (for snowflakes and ice crystals) are performed and the implications for cloud physics, radar measurements of rain and millimeter wave telecommunication networks are discussed.

NONLINEAR EFFECTS ON THE TEMPORAL EVOLUTION OF FLUVIAL DISCHARGE : CASE OF THE OUBANGUI RIVER

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The daily Oubangui river discharge, measured during 59 years, shows a strong one-year cycle, with irregular variations along the time. Our goal is to determine the physical nature of theses modulations (stochastic or chaotic process). Although the autocorrelation time τ is about 3 months, and despite the relative shortness of the time serie (22,220 points), the Grassberger and Proccacia method can be adapted and applied to this time serie. For different pseudo-dimensions p, a pseudo-attractor can be constructed with points of coordinates $(Q(t_i),Q(t_{i+\tau}),....Q(t_{i+(p-1)\tau})$ and the correlation function $C(r)$ is computed, where r is the pseudo-distance. The slope of the plot ln r vs ln $C(r)$ is estimated and converges to a value near 7.5. This implies that the Oubangui river discharge evolution depends on a deterministic dynamical system, with 8 degrees of freedom. Other data analysis methods, like Poincaré sections and Lyapounov exponents may be used to confirm and sharpen this result.
Examination of the relationship between mean precipitations, measured in different stations, mean runoff and bassin geomorphologic characteristics may provide insight into the underlying physical processes influencing the river discharge evolution.

RELATIONSHIP BETWEEN MULTIFRACTAL ANALYSIS OF RAINFALL TIME SERIES AND SPATIAL RAINFALL DATA

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Better description and modelling of spatial rainfall is needed for hydrological applications (eg GCMs and simulations for distributed modelling). One of the best measurements of spatial rainfall fields is from radar. This typically renders in the order of 100 x 100 pixels for each single radar snapshot. This data is too limited for accurate enough estimation of multifractal parameters to distinguish different storm types (which is essential for GCM application).
One technique that we are exploring is using theoretical results to infer spatial multifractal characteristics from temporal ones. Under certain conditions we may regard temporal readings at a fixed site of a moving system as corresponding to an instantaneous section of the spatial field. This allows application of some recent rigorous work that relates multifractal characteristics of sections or "slices" of measures to multifractal characteristics of the measures themselves.

ELECTRICAL ANALOGY OF FRACTAL HYDRODYNAMICAL DISPERSION

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Determination of basic hydrodynamical parameters for pollutant transport in the subsurface area. Mathematical modeling of the hydrodynamical dispersion, with help of random network of tubes with percolation disorder. For each bond of the system, the tracer motion is governed by a convection-diffusion equation, with the drift term accounting for the local bond velocity. This represents an extension of random walks in disordered media to the important case of finite macroscopic flow rates. There is a Poiseuille flow in the tubes, so that the fluid flow problem isomorphic to the current flow in random resistor network. The analogy implies the correspondences: node voltages equivalent to node pressures and link currents equivalent to link fluxes. Based on this analogy a laboratorial electric modell developed to investigate the fractal characteristics of hydrodynamical dispersion. Elaborating of 168 laboratorial experiments changing the transformed electrical properties modeling of hydraulical and geotechnical parameters. Identifying of the dispersion front. Receiving the set of fractal dimension for the dispersion front in [1.38,1.51]

USING MULTIFRACTAL DESCRIPTION OF SPATIAL RAINFALL IN GCMS

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Global Climate Models (GCMs) typically operate on two dimensional spatial grids comprising squares of side 100km or more. The averaging of rainfall over such grid squares results in rainfall intensities that are too low and therefore an overestimation of evaporation and an underestimation of runoff. Current fixes include assuming a negative exponential distribution of rainfall intensities and an arbitrary fractional coverage depending on one of two storm types. There is mounting evidence that rainfall is multifractal and so the incorporation of a multifractal description of spatial rainfall in GCMs offers a more realistic approach to water balance calculations. The application of a multifractal parameterization scheme and a multifractal cascade model within a particular GCM are discussed. Preliminary results using the UK Meteorological Office's GCM SVAT model (Soil-Vegetation-Atmosphere transfer) make comparisons between all the above approaches.

ON FRACTAL CHARACTER OF SOIL SOLID PHASE SURFACE AS REVEALED BY RETENTIVITY FUNCTION

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Many properties of soils influencing their fertility as well as the behavior in ecological processes are determined by geometry of solid phase. It is particularly true for unsaturated soils composing the uppermost part of vadose zone. Usually this geometry is characterized by value of specific surface area thus leaving a lot to know about organization of this surface. In a case if soil solid phase surface exhibits fractal properties, fractal dimension and other fractal characteristics can be used in soils transport functions such as retentivity and hydraulic conductivity. Applying some model assumptions we used the relationship $dW/dh = ah^{D-4}$ (W - water content on volume basis, h - matric suction, D- fractal dimension, a-constant) to study fractal behavior of chernozem and podzolic soils. To determine h we used micropsychrometer method allowing to measure by the same technique suctions as big as 80 bar. We found solid phase surface to follow the rules of fractality ($2.39<D<2.99$) - the better the less was disturbance of a soil structure- particularly for h> 10-20 b.

ON SPACE-TIME SCALING OF CUMULATED RAINFALL FIELDS

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In the study of space-time rainfall it is particularly important to establish characteristic properties to guide both theoretical and modelling research efforts. In the present paper new observational analyses on the scaling properties of time-evolving cumulated rainfall fields are presented, and a theoretical framework for their interpretation is introduced. It is found that the time evolution of the spatial organization of a cumulated rainfall field produces characteristic scaling relationships of spatial variance vs. time. The reproduction of these relationships constitutes a basic requirement for spatial-temporal field generators in order to model important properties of real rainfall fields. It is then shown, on theoretical grounds, what properties the instantaneous rainfall intensity fields must obey in order to reproduce the experimental observations, and how the size of the observation domain affects the scaling relationships. Some current stochastic models of space-time precipitation are finally discussed and analyzed in the light of the tools introduced, to show under what circumstances the models considered give acceptable results. Furthermore, it is shown that the assumption of an exponential time correlation function, used in many current rainfall models, is not compatible with observations.

SCALING BEHAVIOUR OF MACRODISPERSION IN A BROMIDE TRACER EXPERIMENT ON THE FIELD SCALE

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We investigate the scaling behavior of the longitudinal macrodispersivity observed in a bromide tracer experiment on the test site Krauthausen. Based on a geologic characterization, the aquifer is subdivided into three layers. For the rather heterogeneous two upper layers of fluviatile origin, we observe a power law scaling of the macrodispersity according with the scaling law discussed by Neuman (1991). In the deepest and more homogeneous layer, however, we find evidence for asymptotically Fickian behavior. Results are compared to numerical simulations and information obtained from hydrogeologic and geophysical measurements.

MODELING OF CONTAMINANT TRANSPORT WITH HELP OF STOCHASTIC PARTICLE SIMULATION

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In this paper we investigate the simulation of hydrodynamical contaminant transport with help of stochastical particle tracking method in two and three dimensions. Using the random-walk method solving the Fokker-Planck equation with different boundary conditions, named reflecting and non-reflecting wall. The fractal nature of the porous media simulated by statistical games in possession of the fractal dimension of the investigated layer. Fractal analysis of different concentration path lines in central symmetrical case where the Pe number about 0 and for the homogen velocity field case where the Pe number 10-10000 are elaborated. Investigating the sensitivity of the fractal dimension of porous media. One of the result of this article is that the small perturbation of the initially fractal dimension of the porous media results very much changing in the path line.

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NP1/02 Scaling, multifractals and nonlinearity in hydrology.

FRACTAL STRUCTURE OF LARGEST RIVERS OF CENTRAL ASIA

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Changes of climate take place in Central Asian region at present. One of possible reasons of this process is Aral Sea degradation. That is why a problem of investigation of all rivers of the region by various methods is very important. Some of the methods are used in former Soviet Union for many years others are developed unsufficiently till now. One of such methods is modeling of river network using a theory of fractals and selfsimilarity. Validation of theoretical premises of this theory was made for largest rivers of Central Asia - Naryn and Vahsh. Their run-off is not distorted powerfully by economic activity in the mountain part of their watersheds. It was shown that a structure of chosen rivers network satisfies to conditions of selfsimilarity. Some parameters selfsimilarity of the objects were evaluated. They are parameters of empirical laws of river network structure. Dependences of lengths of main on watershed areas were found. Fractal dimensions of Naryn and Vahsh River networks were evaluated.

Results of the investigation can be used in future for evaluation of some parameters of simulation models of a river network structure changing under an influence of various natural and anthropogenic factors. Moreover, investigation of selfsimilarity and fractals of river network can permit to compress an information for its saving.

EMPIRICAL RELATION BETWEEN FRACTAL DIMENSION OF SUPPORT AND AVERAGE ACTIVITY FOR SPACE-TIME RAIN DISTRIBUTIONS; COMPARISON WITH A SPACE-TIME MULTIFRACTAL MODEL.

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We further discuss the two extreme hypothesis concerning the origin of zeros for rain fields: the zeros are due to (i) the rain process itself, which naturally distinguish between "dry" and "wet" areas/periods (e.g. Kadem and Chiou), and (ii) to the thresholding caused by the measuring apparatus (e.g. Lovejoy and Schertzer). An empirical relation is derived between the fractal dimension D of the *apparent* spatial set supporting rain distributions and the local rain average activity R, for different space-time rain datasets inferred from radar reflectivity signals: D varies linearly with $\log(R)$. This is in agreement with the observation of Over and Gupta (1994). However we show with the help of a space-time multifractal model (Marsan et al. 1996) that our result rather supports the second hypothesis (ii).

The success of this model to predict the observed relation is an indication that mulitplicative cascades are pertinent for the dynamical modelling of rain; they correspond to a hierarchy of rainy structures at all scales l, with typical life times t_l varying as $t_l \sim l^H$, where H is a measure of the scaling anisotropy between space and time.

FRACTAL ANALYSIS OF THE SPATIAL DISTRIBUTION OF SOURCE BASINS WITHIN THE CATCHMENT

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The most common approach to extract the channel network from Digital Elevation Models, is to specify a threshold area, S, which is the minimum area required to drain to a point within which a channel forms. It is recognized that different threshold areas will result in substantially different channel networks for the same basin. This paper studies the effects of S, which is also the scale of observation, on scaling and morphometric properties such as the number of sources and the areas of source basins and lateral basins. Twelve basins located in southern France and having their outlet in the Mediterranean sea were extensively studied. The results indicate that morphometric properties vary considerably with S, and that the spatial distribution of source basins can be considered as a fractal Sierpinski space. A simple model based on the procedure similar to the Sierpinski carpet construction is proposed to explain empirical relations between the number of source areas and the threshold, S. The model presents a new approach to estimate basin fractal properties and defines new indices to characterize the spatial distribution of first order basins. This methodology is useful for hydrologists and geomorphologists dealing with river networks and spatial patterns of various basin properties such as vegetation, soil, soil moisture and human activities.

MULTIFRACTAL ANALYSIS AND EXTREMES OF DAILY RIVER FLOW SERIES FOR BASINS FIVE TO TWO MILLION SQUARE KILOMETERS

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Daily operational river flow data from twenty river basins from the continental USA with sizes varying from 5 to $1.8X10^6 km^2$ and durations up to 80 years, were analyzed to deter mine the limits and types of scaling. Although no outer limit to the scaling was found there is a break in the scaling regime at about one to two week time period. This is in a greement with other scaling studies of rain, river flows, temperature and topography and corresponds to the "synoptic maximum" -typical life time of planetary scale disturbances. Despite the varying basin areas and series length, the estimated multifractal parame ters characterizing the infinite hierarchy of scaling exponents as well as the exponents characterizing the extreme self organized critical events, were consistent and close to the river basins from France. We used those critical exponents to theoretically determine the accumulated volume as a function of interval duration. We compared the multifractal and standard treatment of extremes showing that the multifractal treatment is quite superior.

MULTIFRACTAL ANALYSIS OF DAILY RAINFALL DATA

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A spectral analysis of high resolution rainfall data usually shows roughly two different regimes: a $1/f^{\beta}$ spectrum for time scales smaller than several days, and a nearly flat spectrum for scales from days to years. We focus here on the latter scales. Using wavelets for the scale degradation, we show that at these scales the rain field can be modeled with multifractals: because of the white spectrum and the non-Gaussian statistics, these can be called "white multifractals". We estimate several parameters in the universal multifractal framework, using daily rainfall data recorded in more than 100 stations in Belgium since 1951.

Using the latter parameters, we then simulate rainfall time series having the same statistics (and dynamics) as the data. This may be used as input to hydrological models.

SELF-SIMILARITY AND MULTIFRACTALITY OF RIVER PROFILES

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DEM data analysis reveals two statistical scaling properties of river profiles. Let $\Delta h(A, \Delta L)$ be the elevation difference between the section that drains area A and the section downstream at distance ΔL. A first scaling property, of the self-similar (ss) type, holds between elevation drops at different locations along the river. One finds that, with good approximation, $\Delta h(A, \Delta L) =^d r^{-H} \Delta h(rA, r^{0.5}\Delta L)$ for any $r > 0$. A second scaling property applies locally, to elevation drops from any given section to sections downstream at different distances ΔL. This second property is of the multifractal (mf) type: for any $r \geq 1$, $\Delta h(A, \Delta L) =^d W_r \Delta h(A, \Delta L/r)$, where W_r is a random variable. For the profiles we have analyzed, H is zero or slightly positive and W_r has a distribution that is close to either a log-Levy variable with low α or the product of a Bernoulli and a lognormal variable, the latter with small variance. Both mf models are consistent with a "pool-riffle" morphology. The ss and mf properties are unrelated (a river profile may be ss but not mf, or mf but not ss). In some river profiles, H or the distribution of W_r vary somewhat with contributing area A. We show that ss is a property of equilibrium topographies generated by various fluvial erosion models, whereas mf may originate from multifractality of the geologic stratification or the riverbed erosion/deposition/transport processes. Finally, we develop coupled models of the drainage area and river profile processes {A(L), h(L)} that satisfy both global self-similarity and local multifractality.

NP1 Scaling, multifractals and nonlinear variability in geophysics

Convener: Schertzer, D.
Co-Convener: Lovejoy, S.M.

03 Scaling, multifractals and nonlinearity in oceans & atmosphere (joint with OA)

Convener: Schmitt, F.
Co-Conveners: Cahalan, R.F.; Yanovsky, V.V.

Use of Magnetic Susceptibility Methods for the identification of Tsunami deposits in the Tagus estuary

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The Tagus estuary is located in the Portuguese western coast near the city of Lisbon and covers an area of approximately 320 km2. It is a high mesotidal that has been subject to several large tsunami invasions in the past, particularly at 1755 and 1531. In order to identify the sedimentary signature of the tsunami waves, the record of longer-term environmental changes of the Tagus salt marshes was studied, using environmentally-sensitive proxies to identify subtle changes of salinity, depth and temperature during the last 500 years. The analysis of vertical concentration profiles of non-anthropogenic elements indicates relatively homogeneous concentrations, in accordance with the dominant silty to clayey composition of the sediments. However, significant variations were detected for the K/Rb, La/Sm and Hf/Ta elemental ratios, probably representing variations of the sediment source. The major compositional breaks detected in the vertical profiles of these elemental pairs show some correlation with the nannoplankton vertical profiles of taxa diversity and abundance suggesting that the relative contribution of marine water also changed through time. An attempt to refine the interpretation was made, using magnetic susceptibility methods. A very detailed study of two cores taken from the estuary was made, revealing that the existence of two sediment layers, characterised by two maxima of the bulk susceptibility, clearly correlated with the geochemical and nannoplankton profiles, that were probably generated by 1755 and 1531 (AC) tsunami waves.

A THERMODYNAMICS OF FRACTALS BASED ON WAVELET ANALYSIS: APPLICATIONS TO ROUGH SURFACES AND SATELLITE IMAGES OF FRACTAL CLOUDS.

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We elaborate on a unified multifractal description of (2D) singular distributions, including measures and functions, based on the continuous wavelet transform. This new approach relies upon the definition of partition functions from the wavelet transform modulus maxima. We demonstrate that very much like thermodynamic functions, the generalized fractal dimensions D_q and the $f(\alpha)$ singularity spectrum can be readily determined from the scaling behavior of these partition functions. We show that this method provides a natural generalization of the classical box-counting techniques to fractal functions (e.g., the image of rough surfaces), the wavelets playing the role of "generalized oscillating boxes". We illustrate our theoretical considerations on pedagogical examples including (monofractal) fractional Brownian surfaces and multifractal counterparts obtained by low-pass power-low filtering (fractionally integrating) 2D multiplicative cascades. Then, we use this methodology to compare the multifractal properties of measured and simulated radiance fields for stratocumulus clouds at 30 m resolution in the solar (reflected) part of the electromagnetic spectrum.

MATCHED VARIABILITY OF THE TEMPORAL STRUCTURE OF THE GEODYNAMICAL AND GEOPHYSICAL CHARACTERISTICS

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Atmosphere, hydrosphere and lithosphere of the Earth organize the complex multiparametrical planetary system under the outside world influence (solar radiation, lunar tide...). Investigation of the natural (geodyn.and geophys.) longtime series give the evidence of matched temporal structure of suitable processes. For example the variations of angular momentum of planet or length of day are not only under the influence of the orbital parameters, but under the action of global atmosphere and world ocean circulations. The result of nonlinear interaction in the ocean-atmosphere system powerfully depends on the continuously changing conditions: thus, rapid random fluctuations of meteoparameters interact with SOI in a different manner at the El Nino or La Nina phase SO or at the different seasons of the year. We pay special attention to investigation of irregular structure in the range from 40 to 100 days.

SCALING PROPERTIES OF THE SURFACE CHLOROPHYLL FIELD IN THE NORTHERN ADRIATIC

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In order to study spatial structures of two dimensional fields of surface chlorophyll in the Northern Adriatic sea, scaling analysis of chlorophyll satellite images was performed. The Nimbus-7 images processed for chlorophyll with (JRC-ESA algorithm) cover the area between Po river delta and the Istra peninsula and contain 100x100 pixels with a resolution of 1000 m. An empirical investigation of the scaling laws through R/S analysis was done over the available space scales considering zonal rows and vertical columns. The satellite data were transformed into matrices {Cij} (i, j =1,..., 100) representing the surface chlorophyll with index i oriented along parallels toward the east and j along meridians toward south. The preliminary results indicate that the Hurst exponent is larger, and, consequently, the fractal dimension is lower for winter images than for other seasons. This is possibly due to the combined effects of a varying sea productivity and of changes in the circulati! on. This also indicates that temperature changes are not the main factor controlling primary productivity in the Northern Adriatic Sea. The role of the nutrient discharged by the PO river is unclear and is to be addressed in future studies using multichanel images at higher resolution.

TIDAL INTERNAL WAVES IN THE TROPICAL ATLANTIC: NONSPECTRAL AND SPECTRAL APPROACHES

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A method is described for analyzing oceanic fields to determine the velocity and direction of flat wave packets comprising the tidal internal wave field. The wave field is presented as the sum of plane waves each characterized by specific velocity and direction of propagation. A new method to study wave packets is suggested based on wavelet transform. Some numerical results are presented for investigating tidal internal waves on the basis of temperature measurements at 200 m level obtained from 50 moored buoys in the tropical Atlantic. Generation of waves is caused by tidal currents flowing over uneven bottom topography. Characteristics of tidal internal waves measured in the experiment are discussed. The wave length is equal to 60 km while the direction remains quasi-stationary.

Cloud scaling properties and cloud parameterization in the ECMWF Forecast Model.

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Cloud liquid and cloud fraction variability is studied as a function of horizontal scale in the ECMWF forecast model during several 10-day runs at the highest available model resolution, which is presently improving from 60 km (T213) down to 20 km (T600). At these higher resolutions, model plane-parallel albedo biases are reduced, so that models may be tuned to have larger, and more realistic, cloud liquid water amounts. However, the distribution of cloud liquid -within- each gridbox depends on ad hoc asssumptions of cloud 'overlap' which are not necessarily consistent with observed scaling properties, or even with scaling properties produced by the model at larger scales. To study the larger-scale cloud properties, ten locations on the Earth are chosen to coincide with locations having considerable surface data available for validation, and representing a variety of climatic regimes. Scaling exponents are determined from a range of scales down to model resolution, and are re-computed every three hours, separately for low, medium and high clouds, as well as column-integrated cloudiness. Cloud variability fluctuates in time, due to diurnal, synoptic and other processes, but scaling exponents are found to be relatively stable. Various approaches are considered for applying computed cloud scaling to subgrid cloud distributions, beyond simple random or maximal overlap now in common use. Considerably more work is needed to compare model cloud scaling with observations, and this will be aided by not only by increased availability of high-resolution surface, aircraft and satellite data, but also by the increasing resolution of global models.

TURBULENCE MEASUREMENTS IN THE NEIGHBOROOHD OF A STRONG VORTEX

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Whereas most of the measurement and modeling of the energy transfers in turbulence have been done in homogenenous and isotropic geometries, most real flows are strongly inhomogeneous and anistropic. Atmospheric ones certainly are, with large scales structures in the form of larges eddies being commonly generated (tornados, hurricanes, etc.). To help describe these situations, we have studied in the laboratory the closed flow produced in the gap between two corotating disks. In this geometry, a very intense axial vortex is formed. When both disks rotate at the same rate it is stable while it undergoes violent bursting when the disks angular speeds are too different. In both cases, we have performed local velocity measurements at variable distances from the vortex structure and studied how the turbulence characteristics at small scales are influenced. We find that the velocity power spectra show a $u^2(k) \times k^{-\alpha}$ scaling region , with α varying continuoulsy with the distance to the vortex core: starting at traditional $\alpha = 5/3$ values away from the vortex it reaches $\alpha = 2.8$ near the stable vortex , or $\alpha = 1.2$ in the unstable regime. Similarly, the intermittency (described via the structure function exponents) change with the distance to the vortex and with the flow regime. The fact that the energy transfers and the intermittency characteristics are a function of the geometry and temporal dynamics of the larges scales of the flow is of importance in regards to the theoretical and numerical modeling of real turbulent flows.

NONLINEARITIES OF 3D RADIATIVE TRANSFER, ILLUSTRATED WITH BOUNDARY-LAYER CLOUDS

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Radiative transfer —a.k.a. linear transport theory— is trivially linear with respect to the source term but fundamentally nonlinear in every other respect due to the multiplicative coupling between local scattering/absorption coefficients and radiance. Nonlinearity is stronger when multiple scattering dominates photon transport, as is the case in boundary-layer cloud systems. We survey a hierarchy of old and new approaches to radiation transport in finite *variable* optical media modeling cloud systems, broken or not, with an emphasis on treatment of nonlinearity. Ordered by increasing level of flexibility in variability model and/or numerical accuracy, we have:
- standard plane-parallel cloud models, allowing at best a vertical stratification;
- popular linear combinations of the above, according to "cloudy/clear" fractions;
- "stochastic" radiative transfer in binary mixtures, using simple closure schemes;
- nonlinear averaging procedure in the Independent Pixel Approximation (IPA);
- smoothing the IPA field in the Nonlocal Independent Pixel Approximation (NIPA);
- 3D photon-diffusion theory, (almost) analogous to flow in a porous medium;
- numerical 3D radiative transfer, using Monte Carlo and grid-based methods.

To date, only the first two entries have been applied operationally, mostly in remote-sensing and energy-budget applications respectively. We present in closed form a new result for general 3D diffusion theory that underscores the nonlinear coupling at hand. It relates the systematic bias in albedo caused by variability to the spatial correlations in the extinction field and vertical component of the radiative flux-vector field.

DESCRIPTION OF NONLINEAR TRIAD INTERACTIONS IN FLUID DYNAMICS USING TRILINEAR COORDINATES

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Traditionally the nonlinear transfer of kinetic energy between orthogonal modes in fluid dynamics has been described by a kind of convolution of Fourier coefficients, known as 'triad interaction', T_{lmn}. Triad interaction between wavenumbers n, m and l is known to be constrained by a 'detailed conservation' theorem:

$$T_{lmn} + T_{mnl} + T_{nlm} = 0.$$

There have been few applications of triads to observed geophysical flows. Recently Iima and Toh have generalized the triad description, in the case of incompressible flow, from Fourier to arbitrary orthogonal decompositions.
This presentation will introduce the use of 'trilinear coordinates'

$$\begin{aligned} T_{lmn} &= -y, \\ T_{mnl} &= 2^{-1}\left(y + 3^{1/2}x\right), \\ T_{nlm} &= 2^{-1}\left(y - 3^{1/2}x\right). \end{aligned} \qquad \begin{aligned} x &\equiv 3^{-1/2}\left(T_{mnl} - T_{nlm}\right). \\ y &\equiv -T_{lmn}. \end{aligned}$$

to depict in *two* dimensions (x, y), triad interactions between *three* modes. Examples will be presented of triad interactions between orthonormal wavelet modes, computed from NMC-analyzed atmospheric winds during blocked and zonal climate states, and compared with Fourier results.

ANALYSIS OF RADIOBRIGHTNESS TEMPERATURE FIELD OVER TROPICAL CYCLONE

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It is described the results of data processing for radiobrightness temperature fields over tropical cyclone at the square of (1000 x 1000) km. The correlation function, scaling exponents and singularities spectrum are calculated. A some pecularity of structural functions (SF) usage to analysis of radiobrightness temperature fields are discussed and the analytical approximation of SF dependences is given. The existence of inertial range with the power law spectrum is shown. The comparison with scaling of background fields (outside typhoons) is made.

SPECTRAL ANALYSIS OF RADIATIVE FLUX OF HETEROGENEOUS CLOUDS

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Cahalan et al. (1994) proposed the Independent Pixel Approximation to realise a fast estimation of area-averaged radiative fluxes of inhomogeneous clouds. The basic idea of the nonlocal Independent Pixel Approximation proposed by Marshak et al. (1996) is quite similar to that of the IPA, except that the NIPA may be applied to a horizontal scale of averaging comparable to the mean free path of photons. From the point of view of spectral analysis, the estimation of area-averaged radiative fluxes based on the IPA and NIPA is justified by radiative filtering of the IPA radiative fluxes at a horizontal scale comparable to the mean free path of photons. This implies a break in the spectral slope of spectra computed from the fluctuations of reflectance of heterogeneous clouds.
The present study aims to study spectral characteristics of the reflectance, transmittance and absorptance of absorbing heterogeneous clouds for different incidence angles of radiation. It is revealed that spectral characteristics of the radiative fluxes are significantly influenced by the single scattering albedo as well as by the incidence angle of radiation. If the radiative filtering dominates at horizontal scale smaller than the mean free path of photons, there is a re-distribution of filtered energy at horizontal scales slightly larger than this mean free path. This re-distribution phenomenon becomes more important as the single scattering albedo decreases, which implies that the spectral slope of reflectance spectra of heterogeneous clouds differs significantly from that of the IPA. Another important point concerns the phase shift between the reflectance and transmittance. These spectral behaviours of radiative fluxes result from the difference of cloud heterogeneity effects on the scattering and absorption.

UNIVERSAL MULFIFRACTAL ANALYSIS OF GROUND LEVEL PARTICLE DISTRIBUTIONS FROM EXTENDED AIR SHOWERS

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High-energy interactions of gammas and protons with the earth atmosphere have been simulated by means of the CORSIKA-4.50 Monte Carlo code, and the secondary-particle density distributions in the resulting Extended Air Shower, at ground level, have been studied. The fluctuations seen in these distributions show – after that a deconvolution from a white noise component is performed – features typical of a 1/f noise. The sample is then analyzed in order to study its scaling behaviour, which is eventually parametrized by means of an Universal Multifractal approach.

MULTIFRACTAL AND CHAOTIC ANALYSIS OF ATMOSPHERIC TIME SERIES

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The aim of this study is to provide a complete characterization of the integrated reflectivity, liquid water content (LWC) and water vapor content of stratocumulus clouds and as a result to possibly reveal some of the peculiarities of their internal structure. A recently proposed multifractal approach [1] is employed for analysis of the real world atmospheric data. The approach is based on the nonlinearity found in natural phenomena and includes an estimation of nonstationarity and intermittency of the fields. The scale invariant properties are revealed by studying the structure functions of arbitrary order whereas the degree of intermittency is evaluated by singular measures analysis. The results are summarized on a 'bifractal plane'. The LWC data parametrization is in good agreement with the previously reported results [1]. To investigate a possible chaotic behavior the following standard test steps are performed: 1) phase-space reconstruction of the time series using the time delay approach; a first minimum position of the autocovariance function is taken into account; 2) determination of minimal embedding dimension via correlation dimension stabilization.

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UNSTABLE PERIODIC ORBITS AND ATTRACTORS OF NONLINEAR DYNAMICAL MODELS.

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Numerical method for detection of unstable periodic orbits on attractors of nonlinear dynamical systems is proposed. This method requires the similar techniques as the data assimilation does. This fact facilitates its implementation for geophysical models.
Some low-period orbits of the Lorenz model and the barotropic ocean model have been calculated explicitely. The orbits encoding and application of symbolic dynamics is used to classify and identify the detected orbits and find the whole set of fundamental cycles. Application of the cycle expansion theory to the fundamental cycles set allows to approximate some attractor characteristics difficult to calculate directly.

EXPERIMENTAL MHD STUDY OF A LIQUIDE GALLIUM FLOW AT MODERATE MAGNETIC REYNOLDS NUMBERS

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We study the statistical properties of magnetic field fluctuations generated. in the presence of an externally imposed field, by a swirling flow of liquid Gallium. The flow is produced in the gap between two coaxial counter rotating disks. Kinetic Reynodls numbers $R_e = 10^7$ and magnetic Reynolds numbers up to $R_m = 15$ are reached. The imposed magnetic field B_0 is weak and Lorents forces do not react unto the flow. The magnetic fluctuations b are measured inside the flow using a local Hall effect probe. Its power spectra display a $b^2(k) \propto k^{-11/3}$ scaling region, as can be predicted from Kolmogorov's turbulence model. We also observe that the dissipative scale for the magnetic fluctuations is much smaller than that of the velocity fluctuations. in agreement with the very small value of the magnetic Prandtl number of liquid metals. As a result the dynamics of the magnetic field is concentrated in the large scales of the flow. For a given value and orientation of B_0, we have measured the mean value $< b >$ of the field induced by the (large scale) velocity gradients in the flow. At small R_m one finds $< b > / B_0 \propto R_m$ as is well known. For higher values of the magnetic Reynolds number, we have observed non linear effects whith $< b > / B_0$ growing as R_m^2. Interpolation of these measurements predict a critical magnetic Reynolds number $R_m \sim 30$ for the onset of dynamo action in this flow.

QUANTIFICATION OF MULTIFRACTAL DIFFUSION

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Diffusion is one of the key-mechanism in geophysics (pollutant dispersion, radiative transfer,...) as well as for their interaction with biology (predator-prey systems). Geophysical media being extremely inhomogenous, we consider diffusion in multifractal media.
We first recall the limitation of classical methods based on the scaling law of r.m.s distance traveled by particles, as well as the drastic difference between physical time and the number of steps. Indeed, we showed that the exponent of the former misses the anomalousity of the diffusion, with the only exception of monodimensional media, whereas the exponent of the latter is rather spurious.
We show that the anomalousity of the walk can be multifractaly quantified with the help of the hierarchy of the trace-moments of the walks. We test these observables on numerical simulations.

GENERATION OF HETEROGENEOUS CLOUDS BASED ON MORPHOLOGICAL ANALYSIS AND THEIR EFFECTIVE RADIATIVE PROPERTIES

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Most of recent studies on radiative properties of inhomogeneous clouds are based on the inhomogeneous clouds generated with the bounded cascade model proposed by Cahalan et al. (1994) and Marshak et al. (1994). In spite of the fact that the bounded cascade model can duplicate some statistical characteristics of natural inhomogeneous clouds, it has a drawback to generate clouds whose heterogeneity at large horizontal scale is conditioned entirely by first steps of cascades. So, there is a need to develop methods without such drawback, which may generate heterogeneous clouds having the same characteristics as those observed of natural clouds.
In this paper, we develop a method of heterogeneous cloud generation based on the morphological analysis. This method can generate horizontal fluctuations having the almost same density probability function and spectral slope. Furthermore, the generated heterogeneity has the same morphological spectra as the original fluctuations. We tested the method for various types of fluctuations, in particular those generated with the bounded cascade model.
The radiative properties of heterogeneous clouds generated with this method are compared with those determined for the bounded cascade heterogeneous clouds. This comparison shows these two types of clouds have the same area-averaged radiative properties. Based on these results, we discuss effects of cloud heterogeneity of different types on the area-averaged radiative properties and try to define heterogeneity parameters pertinent to the radiative transfer in heterogeneous clouds.

ONE POSSIBLE MECHANISM OF ELECTRIC FIELD SCALING IN A THUNDERSTORM CELL

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It is well known that the large scale electric field and space charge are forming in thunderstorms. But the origin of small stratification is purely investigated now. To understand it, we take into account that charge tranfered per collision (between hydrometeor and small water drop, e.g.) depends on external electric field, charges on the particles and their velocities. We have designed the system of equations which is composed of hydrodynamic equations, movement and Poisson one. Such a forth flow system (large and small cloud particles and ions) has been investigated and examined in thunderstorm cell. The specific flow instability - charging instability, connected with charge transfer mechanism (inductive or noninductive) has been investigated. We have obtained increments and characteristic wave numbers for this unstable waves for the initial, development and dissipation stages of the thunderstorm cell. Our results are in a good agreement with the data of electric field soundings in storms (*Marshall and Rust, Saunders*). According this data, there are many of the small scale field and charge variations on the background of large scale $\sim 800 - 2500$ meters field. The magnitude of the first one can increase the breakdown field. And in this case charging instability can play the principal role in the formation of compact discharge cells ($\sim$ 30 - 150 meters) in the thunderstorm cloud.

SCALING OF THE NATURAL VARIABILITY OF THE ATMOSPHERE-OCEAN SYSTEM

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We present the power spectra of instrumental temperature data from the Global Summary of day database from time scales of 1 day to 100 years. Maritime stations exhibit power spectra proportional to $f^{-\frac{1}{2}}$. Continental stations exhibit a $f^{-\frac{1}{2}}$ spectrum up to frequencies of $f = 1/(1 \text{ month})$ and a $f^{-\frac{3}{2}}$ spectrum at higher frequencies. We interpret these observations in terms of the turbulent diffusion of heat energy vertically in the atmosphere and ocean. A stochastic term is included to model convective instabilities in the atmosphere that randomly advect heat up or down in the atmosphere. The difference between maritime and continental stations results from the coupling of maritime air masses to both the atmosphere above and the ocean below while continental air masses couple only to the atmosphere above with the land acting as an insulating boundary condition. The transition from a continental-type spectrum to a maritime-type spectrum is investigated by averaging spectra from all stations in the database in 2°x2° grid squares. Differences in the spectra as a function of geography and distance from the ocean are investigated. The crossover time scales from the $f^{-\frac{1}{2}}$ to a $f^{-\frac{3}{2}}$ spectra in continental spectra are used to infer the geographic variation of time scales of thermal exchange between continental air masses and oceans.

A NUMERICAL INVESTIGATION OF SOME SCALING PROPERTIES OF ATHMOSPHERIC TURBULENCE

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The time series representing the velocity components of atmospheric turbulence has been processed numerically. Two data sets were used. The first one was recorded at Zimlyanskaya steppe, over the flat ground. The second data set was recorded in Moscow city, near the big buildings.
The covariances, cross-covariances and power spectrum are presented. The vector delay reconstruction technique was used for fractal dimension measurements. The numerical estimation of Levy index also has been performed.

QUASI-SPONTANEOUS VARIATIONS OF PHYSICAL PARAMETERS

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Spontaneous chaotic fluctuations are inherent for complex nonlinear unstable dissipative systems especially when spatio- temporal intermittance of chaos and order occur and the system passes through consequence of bifurkations. Prognosis of development for such system is very difficult and uncertain. as the system can be influenced by extremely weak signal. but if the last one is correctly organized it opens the principal possibility of so called informational correction. management and control of the system. Speaking about spontaneous variations (SV) of physical parameters we pay also attention to relatively simple systems (resistor. filament of torsion pendulum. crystal of quartz etc.). for which we expect stable physical parameters under stabilized external conditions: temperature. pressure. moisture. EM-radiation etc. But the variations of physical parameters nevertheless are observed and their spectrum near to 1/f law. The synchronism of SV in distant points and correlation with Solar activity give evidence that the phenomenon is not purely spontaneous but rather quasi-spontaneous. being induced by some yet not identified external agent.

MULTIFRACTAL ANALYSIS OF 1D AND 2D CLOUD DATA, THE "WAVELET TRANSFORM MODULUS MAXIMA" APPROACH

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In physics and applied sciences, one is often faced with the problem of characterizing very irregular functions. Examples range from plots of various types of random walk (e.g., Brownian signals) to financial or medical time-series, turbulent signals from wind-tunnel or atmospheric studies, etc. Wavelet analysis, a general framework for analyzing signals in space and scale, has been described as a "mathematical microscope" and is well-adapted to reveal the hierarchy governing the spatial distribution of singularities in multifractal measures. The Wavelet Transform Modulus Maxima (WTMM) method is a more recent development. It is based on the continuous wavelet transform and enables us to generalize multifractal formalism to all types of singular processes, i.e., functions as well as measures. With the appropriate choice of analyzing wavelet, it includes standard box-counting and structure-function methods. The WTMM method has been tested on a variety of pedagogical examples and successfully applied to numerical and experimental data from various domains: turbulent velocity, DNA sequences, DLA clusters, etc. After presenting tutorial examples in 1D, we show results for atmospheric liquid water path (retrieved from passive microwave radiometry at the ARM site in Oklahoma) that demonstrate its strong multifractality. We also describe a 2D generalization of WTMM methodology and apply it to high-resolution LANDSAT images of clouds.

BEYOND THE MULTIFRACTAL PHENOMENOLOGY OF GEOPHYSICS: DYNAMICS AND (REVISITED) RENORMALIZATION

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A large class of multifractal models, often called Fractionally Integrated Fluxes (FIF) models, had been developed for modeling of geophysical intermittent fields. Their *static* version have become rather popular for the last ten years for the simulation of contaminants, clouds, rain, topography, etc., whereas their *dynamic* extension is rather recent.
We show that FIF models have a "renormalized viscosity/renormalized forcing" structure: both terms correspond to the relevant contributions from other scales to the evolution of a given scale in a renormalisation procedure. However, contrary to a standard renormalization (DIA, RNG...), the renormalized forcing is far from being quasi-gaussian and the corresponding models do yield wild probability distributions, i.e. strong intermittency.
We therefore revisit renormalization techniques and obtain intermittent models built directly on the structures of the generating equations and not only on their scale invariance.

A SCALE-BY-SCALE VALIDATION OF CONTINUOUS MULTIFRACTAL MODELS IN TURBULENCE

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We consider two continuous (in scale) cascade models: log-Poisson and log-Lévy (a special case of which is the log-normal model). The usual way to validate cascade models is to estimate $\zeta(q)$ defined as $\langle|\Delta V_l|^q\rangle = C_q l^{\zeta(q)}$. This corresponds first to estimate some scale invariant function, and then to use it to estimate the parameters of cascade models. This is useful to eliminate e.g. the log-normal model, but not precise enough to clearly show which one from log-Poisson or log-Lévy models is closer to data: these two models provide excellent fits of empirical $\zeta(q)$ curves up to high order of moment (of about 7).

We therefore propose another approach, which consists in studying the statistics scale-by-scale: we first estimate the parameters of models at a given scale and then consider the scale-dependence of these parameters. This procedure can be done much more precisely than previously, because it is done for a fixed scale, and no more needs a straight-line fit in log-log using least square method. This corresponds to estimate $\Phi_l(q) = \log\langle|\Delta V_l|^q\rangle$, the second Laplace characteristic function of the generator $g_l = \log|\Delta V_l|$ of the velocity shear (it is also called cumulant generating function). Then we precisely estimate the range of values of q for which log-Poisson and log-Lévy models are fitting the empirical data: this clearly shows the validity of the log-Lévy model (with $\alpha = 1.5 \pm 0.1$) as opposed to the log-Poisson model which has no scale-invariant parameter.

TURBULENCE PARAMETRIZATION USING FRACTAL SYNTHETIC FIELDS

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Turbulent fields that are encountered in many geophysical applications have geometric properties that are better described in terms of fractals. This talk presents a new way to express the subgrid stress tensor that arises in Large Eddy Simulation (LES) of turbulent flows by means of synthetic fractal subgrid-scale fields. First, the relevant matematical tool is reviewed. Next, the model is applied to a simple 1D scenario, Burgers equation with a stocastic forcing. Then, the extension to the 3D case is derived, which is used to formulate a subgrid closure. The model is applied to both steady and decaying isotropic turbulence. We find that the assumption of fractality *per sè* is not enough to yield physically meaningful results, and explore several variants of the model in which the rules to generate the synthetic field explicitly incorporate the condition that energy dissipation take place. Good results are obtained only once the fractal dimension is allowed to vary in different eigendirections of the resolved rate of strain tensor as to (nearly) maximize energy dissipation.

SELF-ORGANIZED CRITICALITY : A SIGNATURE OF QUANTUMLIKE MECHANICS IN ATMOSPHERIC FLOWS

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The spontaneous organization of selfsimilar (fractal) space-time fluctuation patterns generic to dynamical systems in nature is identified as self-organized criticality(Bak et.al.1988: Phys.Rev.A.38,364). Atmospheric flows exhibit self-organized criticality manifested as the fractal geometry to the global cloud cover pattern concomitant with inverse power law form for power spectra of temporal fluctuations. Mary Selvam(1990:Can.J.Phys.68,831) and Mary Selvam et.al.(1992:Int'l J.Climatology 12,137)have proposed a non-deterministic cell dynamical system model for atmospheric flows which predicts the observed self-organized criticality as a direct consequence of quantumlike mechanics governing flow dynamics. The model predictions are as follows.(1)Atmospheric flows follow an overall logarithmic spiral trajectory with the quasiperiodic Penrose tiling pattern for the internal structure.(2)Traditional power spectral analyses of such spiral flow structures will reveal a continuum of eddies with embedded dominant wavebands.(3)The power spectra follow the universal inverse powerlaw form of the statistical normal distribution,thereby providing unique quantification for observed self-organized criticality. (4)Climate change induced by man-made greenhouse gas related atmospheric warming will result in intensification of fluctuations of all scales seen immediately in high frequency fluctuations.

NONDIFFUSIVE SCATTERING STATISTICS IN UNIVERSAL MULTIFRACTAL CLOUDS:

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Recently, we developed a multifractal scattering formalism for radiative transfer in multifractal clouds in which the (nondimensional) extinction coefficient κ takes the place of the scaling parameter λ. This allowed us to renormalize the multifractal cloud defining an "effective" extinction coefficient $\kappa_{eff} \approx \kappa^{(1-K'(0))^{-1}}$. (Note, $K'(0)<0$; $K(q)$ is the moment scaling exponent for cloud density); this result requires only analyticity at q=0.

We have now extended this to certain nonanalytic cases (with exponent of nonalayticity $1\leq\alpha<2$; corresponding to universal multifractals), obtaining $\kappa_{eff} \approx (\log\kappa)^{\frac{\alpha}{2}}$. Due to large "Levy holes", photons travel extremely far - even in clouds which are on average very optically thick. The nondiffusive nature of this scattering can be quantified by comparing the most probable distance with the R.M.S. distance; these quantities are nearly equal in thick clouds with analytic K(q) at q=0, but in these universal multifractal clouds, they vary as $\kappa^{-(1+C_1(\alpha-1))^{-1}}$ and $(\log\kappa)^{-\frac{\alpha}{2}}$ respectively. Note that these occasional long distance scatters will - in the presence of water vapour - significantly contribute to anomalous cloud absorption.

TIDALLY INDUCED HETEROGENEITY IN DIFFERENT HYDRODYNAMIC CONDITIONS: A MULTIFRACTAL ANALYSIS

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The multifractal properties of temperature, salinity, *in vivo* fluorescence (i.e. estimate of phytoplankton biomass) and nutrient concentration recorded for time scale of 1 sec to 1 hr were investigated in different hydrodynamical regimes related to tidal forcing. Power spectrum and probability distribution analyses indicate that temperature, salinity and nitrites fields are scaling over the whole range of scales whereas the temporal scaling regime was approximately 1-25 sec for the fluorescence field, and that the whole data were hyperbolically intermittent. The analyses of statistical moments show that variability of these different parameters were well characterized by a multiscaling behavior for low order moments. Moreover, the characteristic spectral exponent β, the first order scaling exponent of the structure functions $\zeta(1) = H$, as well as the basic universal multifractal parameter C_1 determined using the Double Trace Moment analysis technique clearly showed a tidal variability. These results showed that the structuration of temperature, salinity, phytoplankton biomass and nutrient concentration can then be viewed as the result of multiplicative processes, wholly dependent on the hydrodynamical conditions associated with tidal cycle.

A METHOD TO IDENTIFY MORPHOLOGY AND SPATIAL SCALE OF CLOUD SYSTEMS USING FRACTAL BOX-COUNTING DIMENSIONS

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Mesoscale cloud systems are followed in satellite infrared images during their life cycle over the equatorial Pacific Ocean. Using a technique of cloud classification based on IR and VIS radiance, convective tops are separated from thick anvil. Box-counting dimension (Db), graph dimension (Dg) and fraction of clouds (Ac) are computed for the images of systems and convective tops during their life cycle. Through the application of Principal Components Analysis using as variables Ac, Db, Dg for 216 images, eight patterns of clouds have been separated according to their spatial scale and morphology defined by multifractal properties. Time evolution of these patterns are studied for 68 life cycles of cloud systems. Frequency of patterns and how these are related to phase and duration of life cycles are investigated. Predominance and transition of patterns for anvils and convective tops are also shown. Time evolution of structural characteristics related to size, intensity and spatial distrubution of cells are compared to the observed change in morphology. It is shown that, in general, patterns of systems and embedded convective tops are similar, but for most cases convective tops have larger ratio perimeter/area.

MULTIFRACTAL ANALYSIS OF CLOUDS FROM 5000KM TO 50CM AND THE DEMISE OF THE MESOSCALE GAP

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The standard model of the atmosphere assumes that the small and large scales are isotropic homogeneous 3-D and 2-D turbulences respectively, with these two qualitatively different regimes seperated by a meso-scale "gap" in the spectrum at scales of roughly 10km (the vertical pressure scale). Identifying the 2-D turbulence part with the "weather" is the classical justification for the lack of explicit treatment of subgrid processes in numerical weather models. We analyzed over a thousand visible and infra red images from geostationary (GMS), polar orbiting (NOAA 12, 14, SPOT) satellites as well as ground based images (roughly 100 times more data than that used on any comparable study) to study the scaling properties of clouds over the range 5000km to ≈50cm. As predicted by the unified scaling model, the radiance fields are indeed very close to what is expected for universal multifractals. In the latter, the infinite hierarchy of exponents (e.g. dimensions/codimensions) is described by only three universal exponents (H, C_1, α): the nonconservation exponent (H) of the mean field; the mean singularity (C_1) and (Levy) index of multifractality. The clustering over the values of C_1, α near $C_1\approx0.075$, $\alpha\approx1.88$ indicates that the probability distributions/statistical moments of the generator have nearly identical scaling properties over the range 1-5000km. Finally, we compare these results with those of ground based photography, which again shows quantitatively similar scaling.

NP1 Scaling, multifractals and nonlinear variability in geophysics

Convener: Schertzer, D.
Co-Convener: Lovejoy, S.M.

04 Scaling, multifractals and natural/man-made hazards (co-sponsored by NH)

Convener: Salvadori, G.S.
Co-Convener: Malamud, B.D.

INTERPOLATION OF UNIVERSAL MULTIFRACTALS

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One-parameter family of invariants of universal multifractal has been obtained. The existence of such invariants implies the existence of rules allowing one to express higher one-point moments in terms of lower ones. If for a multifractal one finds one of these invariants, this signifies that such a multifractal is in class of universal multifractals with a definite Levy index. A simple algorithm for interpolating universal multifractals based on the invariance discovered has been proposed. The convergence of the algorithm has been proved, and velocity of convergence has been analytically simulated.

SCALING LAWS FOR TROPICAL STORMS AND HURRICANES: A BASIS FOR PREDICTING PROBABILITY OF LANDFALL WIND SPEED

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Scaling laws are proposed for three phenomena: maximum wind speed of tropical storms (34 to 85 knots), maximum wind and speed of hurricanes (>85 knots), and time interval between tropical storms and hurricanes. Note that, traditionally, hurricanes have been defined as storms with wind speeds greater than 64 knots. However, at 85 knots there is an abrupt change from one scaling law to another, which is coincident with formation of the hurricane eye. Therefore, it is proposed that the term hurricane be used only for storms with maximum wind speeds greater than 85 knots. A fractal scaling law is proposed for the frequency of maximum wind speed of tropical storms that have made landfall on the Atlantic and Gulf of Mexico coasts of the U. S. over the past 106 years. An exponential scaling law is proposed for hurricanes. The time intervals between landfall for tropical storms and hurricanes making landfall on the Atlantic and Gulf of Mexico coasts of the U. S. over the past 106 years follow an exponential scaling law. The maximum wind speed frequency distribution of tropical storms that have made landfall on the Atlantic and Gulf of Mexico coasts of the U. S. follows a fractal scaling law, $N = a(w)^D$, where N is the cumulative frequency, a is a constant, w is the maximum wind speed, and D is the scaling exponent, ranging from -0.82 to -1.97 depending on location. This law for wind speed and an exponential law for the time interval between events are used together to calculate probabilities of future tropical storms of a given maximum wind speed as a function of location. The maximum wind speed frequency distributions of hurricanes that have made landfall on the Atlantic and Gulf of Mexico coasts of the U.S. follow an exponential scaling law, $N = a(e)^{bw}$, where N is the cumulative frequency, a is a constant, w is the maximum wind speed, and b is the scaling exponent, which ranges from -0.07 to -0.13 depending on location. This exponential law for wind speed and an exponential law for the time interval between events are used together to calculate probabilities of future hurricanes of a given maximum wind speed as a function of location along the Atlantic and Gulf of Mexico coasts of the U.S.

MULTIFRACTALITY OF CHERNOBYL FALL-OUT AND THE ESTIMATION OF DOSES ACCUMULATED BY INDIVIDUALS.

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We discuss the influence of geophysical turbulence transport on the multifractal complexity of Chernobyl radio nuclides contamination distribution and point out new ways for doses evaluation taking it into account. We present two data sets of the ^{137}Cs cumulative soil deposition collected around Chernobyl: the short range (<150 km) inhomogeneous point like distribution and the middle range (<300 km) homogeneous pixel distribution; the values range from 0,4 to $6x10^5$ kBq/m^2. We proceed to an empirical estimate of the universal multifractal and corresponding critical exponents, which confirm that the highly intermittent field of ^{137}Cs soil contamination is the result of a non classical SOC transport mechanism. We argue that "hotspots" at all scales and at all intensities displayed by the Chernobyl fall-out play a fundamental role for risk assessment and monitoring. Indeed we show that the probability distribution of the doses accumulated by random walkers traveling within a multifractal distribution of contamination can not be characterized by the usual mean dose. We analytically demonstrate that the random walk dimension D_w and the moment scaling function K(q) of contaminated area define a critical moment q_{Dw} after which the PDF of accumulated doses will have algebraic fallout: the probability of having the dose 10 times larger than given dose will by only 10^{-qDw} times smaller.

MONITORING THE REGIONAL AND GLOBAL SEISMICITY BY NATIONAL/REGIONAL DATA CENTERS

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In the European-Mediterranean region, a great number of national and regional data centers monitor the seismicity with different goals: such as exact hypocenter location and fault mechanisms, rapid epicenter and magnitude determination or just purely scientific purposes.
This paper reviews the seismicity of Switzerland of the past 25 years, addressing different aspects of data collection and alarm procedures, location accuracy and magnitude thresholds , as well as the exchange of data with surrounding countries for events near the border.

SELF-AFFINITY AND DYNAMIC SCALING OF EXTREME STORM PRECIPITATION

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The concepts of scaling and multiscaling, developed in the last twenty years, provide a powerful framework for studying spatial and temporal variability of numerous hydrological processes. The areal reduction factor (*ARF*) of storm precipitation, widely used for reducing the point rainfall to obtain areal average values, reflects the scaling properties of precipitation in space and time. The concepts of statistical self-affinity and dynamic scaling are used to understand better the aggregation of extreme rainfall precipitation at different temporal and spatial scales. An analysis of current formulas, generally used to determine *ARF*, shows an inadequacy to reproduce the variability of extreme rainfall. So a new formula for the areal reduction factor, based on this approach, is proposed. Application is made to data in the United Kingdom as reported in the NERC Flood Studies Report and observations from Milan, Italy, ranging from 20 minutes to 12 hours and from about 0.2 to 314 km^2. These studies indicate that the conjecture that storm rates in space and time are self-affine for extreme events, taking in account the relative insensitivity of the areal reduction factor to the probability of exceedance, provides a useful approach to the evaluation of design storms.

A MODEL FOR NUMERICAL SIMULATION OF THE STATISTICAL PROPERTIES OF PRECIPITATION FIELDS

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A multifractal model for generation of synthetic rainfall is presented. The model is based on wavelet decomposition with coefficients extracted by a multiplicative stochastic cascade. The Log-Poisson probability distribution is used as random generator of the multiplicative process. The theoretical derivation of statistical properties of the model shows that synthetic signals follow anomalous scaling laws depending only on two parameters: the expectation of the Poisson distribution c and a parameter β. Properties of generalized extended self-similarity depend only on the β parameter. The optimal agreement between expected and sampled scaling is shown through some examples of Monte Carlo simulations in R and R^2. Scaling laws of real rainfall in time and space were also computed to apply the model for downscaling problems.

MULTIFRACTAL ANALYSIS OF RAINFALL FIELDS IN TIME AND SPACE

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In order to apply multifractal models for downscaling large scale precipitation fields, a multifractal analysis of rainfall in time and space was performed to investigate statistical properties and anomalous scaling laws.
Results of high resolution rain time series recorded in Genova (Italy) display the presence of an external scale, physically coherent with typical extreme storms of the area, around 10÷20 hours: anomalous scaling laws hold in the two ranges of time scales shorter or longer than this threshold. Some synthetic rainfall time series were generated with a new multifractal model based on wavelet decomposition with coefficients extracted by a multiplicative stochastic cascade: the Log-Poisson probability distribution has been assumed as random generator. Synthetic time series have shown very similar statistical behaviour to that observed for the Genova series. The potential of the multifractal model in reproducing extreme rainfall events was also investigated.
Precipitation fields from the GATE campaign and from a numerical simulation with a meteorological limited area model (LAM) were used to perform a multifractal analysis of rainfall in space. Results from GATE fields have shown that spatial scaling of rainfall depends on time duration. Despite the strong simplifications of microphysical processes applied in meteorological models, statistical properties of LAM rainfall fields were very close to the GATE ones.

MEASUREMENT OF CS-137 SOIL DEPOSIT WITH METER SPATIAL RESOLUTION AND EVALUATION OF FRACTAL CHARACTERISTICS OF RADIOACTIVE CONTAMINATION SPOTS

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The investigation of the levels, mechanisms and geometric characteristics of the radioactive contamination spots on soil was carried out. The specific indicator is radioactive isotope Cs-137. The investigation consists of three parts:
i) direct measurements of Cs-137 level in natural conditions;
ii) storing of database on the radioactivity levels in contaminated areas;
iii) determination of fractal characteristics of contamination spots.
The measurements were performed with the device "Corad" developed by the researchers and registering the fluxes of quanta within the chosen energy range. Their minimum resolution is about 1 m. The contaminated area is covered by the registration nets 2 m x 2 m, 10 m x 10 m and 200 m x 200 m with the total number of points about 8000-10000. The line measurements with step 2 m were performed too. After computer processing the data stored in the database. The geometric characteristics of a contamination spot expressed in terms of fractal theory. The fractal dimensions contain the important information on relevant factors determining the spreading of radioactivity. These measurements permit to separate the specific and universal features of contamination and to determine more accurately the dangerous levels of radioactivity.

A SCALE OF COSMIC-TERRESTRIAL CATASTROPHES

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A conception of cosmic-terrestrial catastrophes scaling is developed for the events of small celestial bodies(meteoroids,asteroids,fragments of comet heads)collisions with the Earth. The collisions are divided into classes: air-blast catastrophes (ABC) and impact-collision events (ICC). We also classify various types of the catastrophes respect to damage scale as: local, global those and supercatastrophes.Dimensionless intensities. (magnitudes) of the catastrophes are introduced. Results of several collisions study are used. We suggest to use the Tunguska explosion intensity as a scale unit for ABC events.Logarithm of relative blast energy is recommended for the ABC magnitude. A simple formula for relation between usually used magnitude of a Earthquake and cosmic body energy is derived for the ICC case. Events of the body falling into ocean water and tsunami effect are also considered separately.

A SYSTEMATIC GLOBAL ASSESSMENT OF THE SEISMIC HAZARD

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Quantitative and reliable assessments of the regional seismic hazard can provide a rational basis for construction codes, insurance rates, and levels of hazard preparation. In this paper, a systematic global approach to the hazard assessment is proposed based on the direct association of small earthquakes with large earthquakes. This association is based on Guttenberg-Richter frequency-magnitude statistics. These statistics have been accepted as evidence that earthquakes exhibit self-organized critical behavior. We introduce the seismic intensity factor, the average number of earthquakes per year in a 1° x 1° region with magnitude greater than or equal to four. We present global and regional maps of the seismic intensity factor based on data from the NEIC Global Hypocenter Database from 1963-1994. The seismic intensity factor can be used to estimate the recurrence intervals of an earthquake with a specified magnitude. A comparison is made with a global map of the largest earthquakes that have occurred in each 1° x 1° region in the last 95 years. The limitations of this approach will also be discussed.

APPARENT (?) BREAKS IN FREQUENCY-MOMENT SCALING

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It has been suggested that the finite width of the seismogenic lithosphere can have a strong effect on the power-law scaling of frequency-moment relation for large earthquakes. Theories have been proposed in which large earthquakes have either a shallower or a steeper power-law slope in the *incremental* frequency-moment distribution, at characteristic seismic moments corresponding to earthquakes which rupture the entire seismogenic depth. Many authors have applied the predicted double-slope distribution - requiring five independent parameters - to *cumulative* frequency data, and used the location of the break of slope to make inferences on characteristic size effects in the earthquake source in different seismotectonic regions. Here we examine the problem in a forward modelling mode, by adding a degree of statistical scatter to ideal incremental frequency-moment distributions of various commonly-used forms, including the single slope (Gutenberg-Richter), double-slope, 'characteristic', and gamma distributions. We find that, in each case, the combination of high-frequency noise introduced by the random statistical scatter and the more gradual natural roll-over in the cumulative frequency data near the maximum seismic moment can produce apparently convincing, but in fact completely spurious, 'double-slope' distributions, even when this is not present in the underlying distribution. We conclude that simpler solutions to the frequency-moment problem should be adopted for seismic hazard applications until sufficient data exists to resolve such effects uniquely. The simplest generic frequency-moment distribution, consistent with existing short-term earthquake catalogues and longer-term finite tectonic moment release rates, with modern theories of earthquakes as critical phenomena, and requiring the minimum number of independent variables (i.e. three), is the gamma distribution.

WHY DO FOREST FIRES OBEY POWER-LAW (FRACTAL) FREQUENCY-AREA STATISTICS?

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Forest fires and wildfires are clearly very complex natural hazards. Yet, as we show, they obey power-law (fractal) frequency-area statistics in a very robust way. Five fire datasets satisfy the relation $N_f \propto A_f^{-\alpha}$ (N_f the noncumulative number of fires with area A_f). The regions include Southern California, Australia, Alaska, and the whole of the USA. The time periods range from 2 to 800 years of data (the last from tree rings). Although these datasets are from very different regions and time periods, each exhibits very similar power-law exponents ($1.3 < \alpha < 1.5$) with excellent power-law fits. Two quite different "forest-fire" models have been previously proposed. The first is a site-percolation, critical-point model in which the probability of a tree being on a site (considering a square grid of sites) is specified. Power-law statistics are only found in the vicinity of the "critical" value of this probability. The second model is the self-organized critical "forest-fire" model, in which trees are continuously planted and matches dropped at $1/f_s$ time steps, where f_s is the sparking frequency. In this case, power-law (fractal) statistics are found for all values of the tuning parameter (the sparking frquency). It is concluded that small forest fires are a necessary condition for the establishment of tree clusters that have power-law frequency size statistics.

SCALE INVARIANCE OF STORM SURFACE RUNOFF

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The conjecture that extreme storm probabilities display scale invariance for a wide range of temporal scales yields simple models for prediction of design storms. For example, the analysis of annual maximum rainfall data for durations from 1 to 24 hours in the Po river valley indicates that simple scaling cannot be rejected for more than 90% of 390 stations in an area of about 70,000 km^2. Because of nonlinear hillslope response, also including threshold effects, one is interested in assessing also the scaling properties of surface runoff as produced by extreme storm rainfall. We address this problem by deriving direct runoff from simple scaling extreme storms as represented by Intensity–Duration–Frequency (IDF) curves in the form of a power function of duration with constant exponent n for any frequency level. Four infiltration models are used to derive surface runoff, namely, the Philip's equation, the Horton's equation, the Green and Ampt method, and the SCS Curve Number method. It is shown that surface runoff rate r scales as a power function of runoff duration t_r i.e., $r \propto t_r^{-m}$, for the four investigated models and a wide range of normalized infiltration parameters. Note that power law scaling only emerges if runoff duration t_r is properly evaluated from storm duration and ponding time. Although the value of m asymptotically achieves that of n, it strongly depends upon frequency, so one figures out that surface runoff is multiscaling. This property is also examined for the investigated infiltration models.

ANALYSIS AND MODELING OF THE FREQUENCY-SIZE DISTRIBUTION OF LANDSLIDES

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Power spectral analyses of soil moisture variability are carried out from scales of 100 m to 10 km on the microwave remotely-sensed data from the Washita experimental watershed during 1992. The power spectrum $S(k)$ has an approximately power-law dependence on wave number k with exponent -1.8. This behavior has important consequences for the frequency-size distribution of landslides. We present the cumulative frequency-size distributions of landslides induced by precipitation in Japan and Bolivia as well as landslides triggered by the 1994 Northridge, California earthquake. Large landslides in these regions, despite being triggered by different mechanisms, have a cumulative frequency-size distribution with a power-law dependence on area with an exponent ranging from -1.5 to -2. We use a soil moisture field with the above statistics in conjunction with a slope stability analysis to model the frequency-size distribution of landslides. In our model landslides occur when a threshold shear stress dependent on cohesion, pore pressure, internal friction and slope angle is exceeded. The cumulative frequency-size distribution of domains of shear stress greater than a threshold value with soil moisture modeled as above and topography modeled as a Brownian walk is a power-law function of area with an exponent of -1.8 for large landslide areas. This distribution is similar to that observed for landslides.

Geometric Scale-Invariance in Transformation-Induced Faulting

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Observations of seismogenic regions and faults even at the microscopic scale often obey fractal statistics and power-law scaling. These phenomena appear not only with faults at the crustal scale, but also with the micromechanics of faulting. Transformation-induced faulting, a leading candidate mechanism of deep-focus earthquakes, may also be expected to show similar statistical characteristics to brittle systems. This mechanism involves transformation of metastable olivine under stress at conditions just sufficient for nucleation of it's denser polymorphs. The result is formation of numerous micron-scale lenses ("anticracks") of the nanocrystalline stable phase that coalesce as they grow to form a network of much weaker material, which allows macroscopic faulting. We analyzed optical and SEM images of two recent experiments conducted at 2.7 GPa in Mg_2GeO_4 olivine. One was stopped at the verge of shear failure, while the other transformed extensively and localized shear but had no rapid stress drop. Despite their different histories, these experiments developed similar fractal structures. Individual anticrack structures have fractal perimeters of D=1.30-1.35, higher than the coalesced network (D=1.18). These results suggest different dynamics involved in the growth and coalescence of anticracks and network structures. We also measured the maximum radius of individual lenses of stable phase which had not yet fully coalesced into a developing network. We find that the data are almost log-normally distributed, similar to the distribution of microcrack lengths observed in brittle-field experiments. Because transformation-induced faulting leaves distinct mineralogical traces, we propose that it may serve as a vehicle for studying the more general phenomenon of shear failure.

METHODLOGY TO LOCATE GEOLOGICAL RISK FOR INSURANCE: AN APPLICATION FOR THE S. EUFEMIA AREA (CENTRAL CALABRIA, ITALY)

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In the aims of a CEE-POP project, criteria were developed to estimate geological risks along the "S. Eufemia-Catanzaro Isthmus." One criteria was based on the study of historical recurrence of more common and dangerous events in the area, including landslides, river floods and earthquakes. A second criteria was based on mapping of hazardous sites with associated vulnerability. The aim was to have a result immediately usable for the needs of an insurance system. The mapped data included: 5 lithology classes, 6 vegetation covers, 5 landslide typologies, 2 erosion intensity classes, 2 flood hazardous areas, 2 seismic amplification classes, and 3 urbanization conditions. Other related parameters included slope morphology, hydrogeological condition, structural weakness, and active faults. Both were collected at the 1:25.000 scale and digitized using ARCINFO, thus supporting multiparameter cross-correlation on mesh areas of 100 m^2. Detailed data on estimated phenomena recurrence, vulnerability, and esposition were furnished for each cell. A new methodology was used in the landslides classification, using five hazard typologies on the base of the tendency to reactivate themselves in time (instantaneous, pluridecennal recurrent, secular recurrent, plurisecular recurrent, continuous) while the relative vulnerability was based on the supposed rapidity of pre-rupture phase acceleration.

GROWTH AND ARREST OF EARTHQUAKES

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Classical theory predicts that earthquakes growing in a homogeneous stress field should not arrest until the fault boundaries are encountered. However, earthquakes on natural faults, where stresses are heterogeneous, are observed over a wide range of sizes, characterized by the Gutenberg-Richter scaling relation. Here we suggest that heterogeneity should be characterized by the Hausdorff dimension H of the walk associated with a stochastic stress difference field. The critical value for arrest, H = .5, corresponds to a Brownian Walk through the stress difference field $\Sigma(x,t) = \sigma^F(x,t) - \sigma(x,t)$, where $\sigma^F(x,t)$ is the stress failure threshold on the fault, and $\sigma(x,t)$ is the current shear stress. The growing rupture eventually encounters regions where the difference between the strength and the stress is large enough to inhibit further growth. Because of the stochastic nature of the $\Sigma(x,t)$ field, the rupture is no longer able to propagate as a classical object by concentrating stress at the crack tips. In this talk, We present theory and simulation results that support these ideas.

DYNAMIC TRIGGERING OF SLIP IN EARTHQUAKES

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Recent observations and models reported by Gomberg et al. (Bull. Seism. Soc. Am., **87**, 294, 1997) indicate that transient dynamical strains from an earthquake on a fault can trigger earthquakes on faults at near to far field distances from the slipping fault. Evidently the amplitude of the pulse needed to promote triggering is inversely proportional to the wave frequency. We consider the physics of this problem in the context of simple meanfield models of frictional sliding on faults in which the physics is obtained from a Lyapunov energy functional. In this case, one can easily compute the susceptibility χ of slip on the fault to the stress forcing due to the pulse. χ therefore represents the threshold, and for these models with linear Lyapunov functionals, can be shown to vary inversely with wave frequency. While these results do not constrain the details of the frictional physics or the Lyapunov functional, they do provide a theoretical rationale for the observations.

A FRACTAL SCALING LAW FOR TSUNAMI RUNUP

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Tsunamis are sea waves generated by earthquakes, volcanic eruptions, landslides, or, in rare cases, by meteor impacts or man-made explosions. They are a natural hazard for many coastal regions worldwide including the Western United States, Alaska, and Hawaii. Tsunami size can be measured in terms of runup, which is the maximum vertical height that the wave reaches on land above a reference sea level. Runup height can vary from less than a meter to at least 525 meters (measured at Lituya Bay, Alaska on July 10, 1958, and associated with a magnitude 7.9 earthquake.) We find that, for the past century, the cumulative frequency of tsunami runups at several sites around the Pacific rim each follow a fractal (power) scaling law, with a scaling exponent that ranges from -0.63 to -2.9 depending on various factors including local topography and the location and type of energy source. For individual sites, it appears the scaling exponent is constant over different time intervals. For instance, at Ayukawa, Japan, the scaling exponent is the same (-1.1) for the interval from 1896 to 1939 and for the interval from 1940 to 1982, which suggests that the data are stable over the sample intervals and may be sufficient for extrapolation to larger events and forecasting over similar time intervals. We use the scaling law for tsunamis as the basis for probabilistic forecasting of the size and number of future runup events.

EARTHQUAKES IN SOUTHERN FRANCE - RISK ASSESSMENT FROM A REINSURER'S POINT OF VIEW

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Applied to the example of Southern France, this lecture has the aim to illustrate, from a reinsurer's point of view, possible ways of assessing the potential earthquake risk in areas with comparably low seismicity. Although records of earthquake activity in France go back over 900 years, there has been only a small number of intense events. The highest intensity recorded in Nice was about IX on the Mercalli Scale which occurred in the year 1564. An event in Menton near Nice on 23 February 1887 is thought to have reached an intensity of VII to VIII in Nice. A slight tremor in April 1995 caused superficial damage to some buildings in the Principality of Monaco near Nice. It is conceivable, therefore, that a moderately serious earthquake could affect some areas of France in the future, particularly in the south-eastern region. For reinsurance companies, and in particular those focusing on catastrophic low frequency / high severity events, it is of primary importance to conduct a reliable risk assessment, on a case-by-case basis, with the aim to derive suitable premiums also in low seismicity regions. In principal, this goal can be achieved by applying methods involving an appropriate weighing of the four factors seismicity, vulnerability, geographical distribution of values and insurance conditions.

PHENOMENOLOGICAL MODEL WITH FEATURES OF SELF-ORGANIZING NON-EQUILIBRIUM SYSTEM FOR SAFETY MONITORING OF UNSTABLE ROCK SLOPES

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In engineering geology, an interpretation of monitoring data provided by observation of development of rock slope failure enables us to make time prognoses of catastrophically rapid collapse of the slope in question. The empirical-inductive phenomenological model was set up to highlight the interpretationally, diagnostically and prognostically useful features of movement activity on cracks which represent individual key sites of different functional levels within a system of slope failure in the course of a rock fall preparation. Its empirical part was based mainly on the data from 15 years lasting operation of regional safety monitoring system on sandstone rock walls in NW Bohemia. The inductive one - applying also synergetics, made the unifying arrangement of the partial empirical data in the frame of the full-scale sequence and to fill up the gaps in our experience. The model has a form of developmental sequence of characteristic geometrical patterns as they are visible in plots of dilatometric records of relative displacement on rock cracks. Hierarchical, non-linear, discontinuous and semi-cyclical nature of demonstration of activity of the slope movement in time and space with morphological similarity of curve undulations as between the different hierarchical levels of description of the same plot as well between plots from different dilatometric sites representing different system levels of the functional structure of the slope failure in question are stressed. Those features must be regarded in all our slope monitoring activity, data processing and interpretation to avoid as distortions in our grasp of the process under inquiry as well to avoid interpretative and prognostic errors.

PREDICTION OF CATASTROPHES: A NEW APPROACH

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We have determined that catastrophes, as they occur in various disciplines, have similarities both in the failure of standard models and the way that systems evolve towards them. We present a non-traditional general methodology for the scientific predictions of catastrophic events, based on the concepts and techniques of statistical and nonlinear physics. This approach provides a third line of attack bridging across the two standard strategies of analytical theory and brute force numerical simulations. It has been successfully applied to problems as varied as failures of engineering structures, stock market crashes and human parturition, with potential for earthquakes. Extensions of the theory for future research comprise the prediction of societal breakdowns, terrorism, large scale epidemics, and of the vulnerability of civilisations.

ST6 Nonlinear dynamics in the heliosphere (joint with NP)

Convener: Macek, W.M.
Co-Conveners: Carbone, V.; Grappin, R.

ALFVÉN WAVE COLLAPSE IN THE SMALL-DISPERSION LIMIT

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Dispersive Alfvén wave trains propagating along an ambient magnetic field are circularly polarized and their envelope obeys the scalar nonlinear Schrödinger equation, with possible coupling to magnetosonic waves. According to the β of the plasma, convective or absolute modulational instabilities with respect to transverse perturbations lead to Alfvén wave filamentation with possible formation of sharp acoustic fronts.
For weak dispersion, this collapse proceeds with a roughly circular polarization, up to a critical transverse scale $l_\perp$ such that $\frac{l_\perp}{\lambda} \approx (\frac{l_d}{\lambda})^{-1/2}(\frac{\delta B}{B_0})^{-1}$ where l_d measures the characteristic dispersive length, λ the Alfvén wavelength and $\frac{\delta B}{B_0}$ the relative amplitude. The wave then ceases to be circularly polarized and its amplitude saturates. In this regime, the envelope dynamics is governed by a vector nonlinear Schrödinger equation with anisotropic diffraction. Small scales are still formed but instead of foci, very strong gradients develop on elongated structures.

SPACE – TIME DYNAMICS MODELING OF INTENSIVE ALFVEN WAVE COLLISION IN SOLAR WIND PLASMA

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Space-time collision dynamics of intensive Alfven waves in Solar wind plasma is analyzed on the basis of the magnetohydrodynamic conception. For this purpose a special computer program realizing MHD equations in one-scale approximation and making possible to carry out calculating experiments in dialog regime was used. In numerical experiments Alfven wave transformation into magnetic sound and the influence of given disturbances scales correlation on result of their interaction were studied. Simulation confirms phenomenon of reflection from the regions of abrupt parameters' change, which are sensitive to space scales of interacting objects. Obtained results are the illustration of the intensive Alfven wave interaction process, carrying the high level of magnetosound disturbance in Solar wind.

SCALING GYROSCOPE CASCADE MODELS AND THE MULTIFRACTAL MHD INTERMITTENCY.

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Hydrodynamics intermittency has been often investigated with the help of some simplified caricatures of Navier-Stokes equations. Well-known examples are the Burgers equation and shell-models.
Since the spatial dimension is absent in shell-models, whereas it is crucial for the development of intermittency, a more complete model was needed. For hydrodynamics, we developed such a model - the Scaling Gyroscope Cascade (SGC),- by keeping only certain type of interactions of the Navier-Stokes equations. In order to take into account the spatial dimension, while keeping an exponential discretization of scales, we introduce a tree-structure of eddies. Along this tree-structure the equations of evolution due to direct interactions between eddies and sub-eddies are analogous to the Euler equations of a gyroscope. The corresponding indirect interactions are obtained by coupling an infinite hierarchy of gyroscopes.
We present a simple and natural extension of the SGC to the MHD case. Based on the considerations of the structure of the full system of equations, the MHD SGC could be interpreted as a result of superposition of two similar type cascades. We show the relevance of the SGC models for an investigation of multifractal MHD intermittency and transitions to Self Organized Criticality for extreme events.

MAGNETOHYDRODYNAMIC SOLITARY WAVES: RELEVANCE TO SOLAR WIND OBSERVATIONS

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Inclusion of Hall current and/or finite Larmor radius (FLR) corrections introduce dispersion into the standard ideal MHD theory and provides the existence of solitary MHD waves. Unlike most of the studies on solitons in collision-free plasmas, which are based on weakly non-linear, time-dependent, evolution equations (KdV, DNLS), we start from the fully non-linear basic system and isolate solitary waves from the family of 1D stationary waves with the help of the fixed-point analysis. Spatial structures are presented and the strong influence of the plasma thermodynamics is pointed out. Relevance of these solitons to solar wind observations (magnetic holes, interplanetary field enhancements) is suggested.

MIXING OF THE HELIOSPHERIC MAGNETIC FIELD LINES

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The nature of the fluctuation of the heliospheric magnetic field is investigated based on Ulysses observations. A novel method, the spinor formalism is applied to discern between various types of inhomogenities. Among those, the separation rate of the adjacent magnetic field lines is studied in detail, including its dependence on the spatial scale of the inhomogenities. It is argued that the separation leads to the mixing of field lines, which is an important constituent of the cross-field diffusion of energetic particles.

SHOCKS AND ANTISHOCKS IN THE MHD–THOMAS MODEL

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We study the fronts in the 1-D Thomas model of MHD at large magnetic Prandtl number. In a preliminary numerical study, Passot observed a shock configuration, reminiscent of the *th* profile of the stationary Burgers shock. Prompted by this finding, we solved exactly the stationary case at infinite Prandtl number; four families of solutions are relevant in the physical context; they exhibit a *th* profile for both fields, with the same width but a different amplitude, possibly with a minus sign (antishock). We also performed a numerical study of the dynamics at large Prandtl. At times of order unity, some stationary configurations seem to be attractive; for example an initial condition with a negative velocity gradient tends to a configuration displaying a v-shock and a b-shock or b-antishock. We studied quantitatively this evolution by fitting locally the fronts by the exact stationary profiles, hence obtaining a precise description of the temporal evolution of the front width. A good agreement was obtained with an independent calculation of this width, based on its relation with the logarithmic decrement of the exponential fall-off of the energy spectra at very small scales. At much larger times, some of the stationary configurations appear to be only metastable. In particular the solution found by Passot evolves towards a configuration with a b-shock and a v-antishock. This may be interpreted in terms of rarefaction waves. One of our conclusions is that when fronts are present, they are locally well described by our stationary solutions.

FINE STRUCTURE OF COLLISIONLESS SHOCKS: THEORY AND OBSERVATIONS

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Well-accepted theoretical model of a quasi-perpendicular collisionless shock assumes that the shock front is one-dimensional and time-independent. With these assumptions the three-part structure of the high Mach number supercritical shock (foot, ramp, and overshoot) is qualitatively explained as produced due to the interaction of ions with the quasistationary electric and magnetic fields in the shock front. However, quantitative description is still lacking. The foot length is determined only by an order of magnitude, and it is unknown what determines the ramp width. On the other hand, observations show that there is no typical high Mach number shock profile, and the shock fine structure is rich, varying from almost stationary to clearly nonstationary (oscillating, for example). The shock front appears to be substantially structured, with the smallest quasi-stationary scales of the order of $0.1(c/\omega_{pi})$. We review the model of the one-dimensional stationary shock and observational evidence, together with the implications for further theory development.

ROLE OF CORONAL CONDITIONS IN THE DEVELOPMENT OF STREAMS, INSTABILITIES AND TURBULENCE IN THE SOLAR WIND

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In view of understanding the relation between coronal conditions and turbulence in the solar wind, we consider the problem of generating a stellar wind, using axisymmetric MHD simulations in an open domain containing the acceleration region. The magnetic field is the sum of an given external field and an induced field generated by the flow, the latter being rapidly dominant as distance increases. Various intensities and topologies of the external field are considered.
In the non-magnetic case, the existence of streams requires thermal inhomogeneities in the corona. Streams are then unstable if the thermal fluctuations are large enough, and the turbulent regions are the wakes of the (slow) cold streams embedded in between (hot) fast streams. The radial distance for turbulence onset and turbulent dissipation depend critically on coronal turbulent properties. A moderate magnetic field will act as a filter, restricting the existence of turbulent wakes to regions above closed magnetic field lines, above coronal streamers. The case of strong magnetic fields (i.e., low beta), is currently under investigation.

Analysis of the Seasonal Transport of Ozone and Water Vapor into the Lower Stratosphere

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The composition of the lowermost stratosphere is influenced by both the transport of well aged stratospheric air into the lowermost stratosphere, and the incorporation of fresher air more recently transported through the tropical and subtropical tropopause. Using model analysis, satellite data and chemistry codes the relative importance of these two processes are diagnosed as a function of the time of year in both hemispheres.

Arc-Polarized Discontinuities in the Solar Wind: Multispacecraft Studies

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We further examine the properties of rotational discontinuities in interplanetary space. We discuss the polarizations of the discontinuities relative to the ambient magnetic field and the solar wind velocity. The relationship of all RDs (regardless of polarization) with regard to Alfvén waves will be discussed. We will show that the Alfvén waves are phase-steepened with the RDs representing the phase-steepened front. We present a model explaining these waves as spherical waves with arc polarization.

We attempt to determine the direction of propagation of the waves using a spacecraft technique. We will compare the true RD direction of propagation to that of the minimum variance and intermediate variance directions.

ON THE INTERACTION BETWEEN HELIOSPHERIC MAGNETIC FIELDS AND LOCAL INTERSTELLAR MEDIUM IN THE HALE CYCLE OF SOLAR ACTIVITY

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It is known that during the moving of solar system in the apex direction relative to the local interstellar medium the latter exerts an action on the heliospheric structure making it nonspherical like a structure of the Earth's magnitosphere. It has been shown that if the rotation of the Sun is taken into consideration then its rotational velocities reveal a seasonal longitudinal nonuniformity with an annual periodicity. This effect manifests itself in studying both of rotation of the global large-scale magnetic structures (mean solar magnetic field) and rotation of the magnetic fields of active regions (flux solar radiation at $\lambda = 10.7cm$). For these structures of different scales the seasonal longitudinal nonuniformities of the rotation (acceleration or slowdown of the rotation relative to its average annual value) are opposite-in-phase so they can not be explained by the peculiarities of the Earth's orbital motion. There appears to be nonlinear counteraction effect within the system of the interrelated magnetic fields. The dynamics of these nonuniformities has been studied during the 22-year Hale cycle of solar activity using the data sets from 1976 to 1997. Some peculiarities of the dynamics of these effects have been discussed.

WAVELET ANALYSIS OF GEOMAGNETIC TIME SERIES

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Within the framework of the project "Global Field Line Eigenmode Study" geomagnetic Pc3 and Pc4 types of pulsations are investigated. These phenomena are generated either by the solar wind or by the resonances of the lines of geomagnetic field. Baransky et al. published a method, called gradient method, to distinguish between the two possible driving forces of a given pulsation. This method uses the dynamic cross Fourier analysis of magnetic D or H component time series recorded at two stations located on the same geomagnetic meridian about 100-200 km apart. The fine spectral structure of the pulsations, i.e. their exact commencements and ends or their real frequencies, however, can not be appropriately determined from the spectrograms. The aim of this paper is to provide a tool to improve the resolution in the time-frequency domain with the use of simple and cross wavelet spectrum analysis. The authors expect that this type of analysis gives a better insight to the origin and dynamics of the resonances of both types.

ON THE UNIVERSAL IMPORTANCE OF SMALL SCALE ELECTROSTATIC STRUCTURES IN ACCELERATION/HEATING PROCESSES

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It was recently discovered by the Wind spacecraft that small scale coherent, electrostatic structures exist in the solar wind. They present important similarities with the structures already observed in the magnetosheath, magnetotail (observations by Geotail and Galileo) and in the auroral zones (observations by Viking and Freja). In a systematic way, this type of microscopic turbulence seems to be related to a dissipation of energy in the plasma and could thus be a very general ingredient of the acceleration/heating processes. The characteristics of these structures, their relationships to particular physical conditions and range of parameters will be discussed on the basis of the available observationsP and their potential importance in the acceleration/heating mechanisms will be analysed.

ON THE SPECTRUM OF MAGNETIC FIELD FLUCTUATIONS IN THE SOLAR PHOTOSPHERE

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It is known that the fractal structure of the IMF depends on the structure of the magnetic field in the photosphere and the MHD turbulence in the solar wind. In this report we consider the process of generation of small-scale mag- netic fluctuations (<1000 km) by turbulent mo- tions of partially ionized gas in the photo- sphere. Using the model of weakly conducting fluid and assuming quasineutrality and isothermality, the relation between the magnetic field fluctuations and a random velocity field is derived from Ampere's law. Taking into account the Kolmogorov picture of the turbulence in the photosphere, an expression for the wave-number spectrum of the magnetic fluctuations is ob- tained. This spectrum is described by a power law dependence and discussed in the report.

SYNERGETIC PROCESSES ON THE SUN AND THEIR RELATIONSHIP WITH SOME OBSERVATION DATA

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Corresponding to the basic conceptions of synergetics, in this paper is considered the possibility of realization of self-organizing processes on the Sun, which are expressed in the appearence of non steady-state periodic component in the solar energy transfer. The latter can be a natural cause for the observed characteristic pulsations of the Sun (T=160 min). They have no yet any satisfactory explanation. Up to now is accepted that the two thermonuclear cycles in the Sun: proton-proton (p-p) and carbon (CNO), are steady-state and have constant rate. It is supposed in the present paper that in reality exists a basic steady-state component of energy transfer. It follows the p-p cycle and is mixed with a non steady state component, which is connected with a non uniform (pulsations) regime of realization of the CNO-cycle. The latter has autocatalitic character and a strong temperature dependence of the different thermonuclear reactions. The nuclear system is described with the equations of Lotka-Volterra, which are solved for different temperature models. For the periods of oscillations $T=10^3 - 10^4$ s are obtained.

A COUPLED ICE SHEET-VISCOELASTIC EARTH MODEL AS A TOOL TO ASSESS THE PRESENT-DAY IMBALANCE OF THE GREENLAND ICE SHEET

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The present-day imbalance of large ice sheets is of great concern because of their potential contribution to global sea-level change. Unfortunately, the inference of this imbalance from either mass-balance measurements or from radar altimetry data is not very satisfactory yet (poor data coverage, controversy in satellite data..). An alternative method to derive this imbalance is to model the past behaviour of the ice sheet and to analyse the present evolution. Additionnaly, the gravity perturbation (from both ice and deep Earth spatial redistributions) can be used as a proxy so that coupling the ice sheet with a viscoelastic Earth model offers a new possibility of constraining the modern imbalance. This presentation aims at specifying how such a full ice sheet-Earth coupled model can help in extracting the elastic component from the total elastic-viscous gravity anomaly (which is actually measured) and also allows to correct for the height dependency in gravity values (free air gravity) by providing the crustal displacements. The patterns for the different gravity anomaly components as well as the present ice sheet imbalance given by the model for Greenland will be presented. These first results set the basis for a discussion on the possibilities of using field data to constrain the present-day imbalance of ice sheets.

TESTING FOR FRACTAL STRUCTURE IN THE LOW-SPEED SOLAR WIND IN THE INNER HELIOSPHERE

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A time series of velocity fluctuations of the low-speed stream of the solar wind measured by the Helios spacecraft in the inner heliosphere is analysed. We invoke a modern method of singular system analysis to give a faithful representation of a fractal structure in the solar wind. In this way, the data are represented in terms of a complete set of orthogonal functions, obtained from a numerical analysis of the data, and not imposed from outside, as is in Fourier analysis or wavelets representations. It has been shown that singular system analysis is the powerful method of the reduction of the inherent experimental noise in the experimental data. This results in better characteristics of the structures and proves that this method is more adequate than a standard moving average smoothing. Furthermore, the obtained characteristics of the fractal structure are significantly different from that of the surrogate data. Thus the results of these tests suggest that the inner heliosphere is *nonlinear* deterministic system, at least in the inertial manifold of the phase space of this, as a whole, complex high-dimensional system.

OSCILLATORY DISINTEGRATION OF NONEVOLUTIONARY SHOCK WAVES

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We suggest a new scenario of nonlinear evolution of nonevolutionary MHD discontinuities. For such a discontinuity the problem of time evolution of its small perturbations does not have a unique solution. Therefore, it cannot exist as a stationary configuration and must disintegrate or transform to a more general nonsteady flow. Evolutionary are fast and slow shocks, while trans-Alfvénic shocks (TASWs) are not. This conclusion is valid for the shocks with both planar and nonplanar structure. The key feature of TASWs is that their disintegration configurations necessarily include an Alfvén discontinuity (AD) that is also nonevolutionary in the presence of arbitrarily small but nonzero dissipation. We show that the contradiction inherent in the nonevolutionary shock is removed if its evolution has the form of oscillatory disintegration, i.e., reversible transformation to the AD. We also apply the principle of evolutionarity to dissipative discontinuities in the profile of inviscid supercritical shocks. Using this approach, we obtain the conditions under which such shocks cannot exist as a stationary flow. In analogy with the shock as a whole, the nonevolutionarity of the internal discontinuity results in oscillatory reformation of the shock structure. We argue that the nonevolutionarity of TASWs is the reason why they are observed in the heliosphere much more rarely than fast shocks.

STRUCTURE FUNCTIONS AND SCALINGS ANALYSIS OF SOLAR WIND FLUCTUATIONS

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The solar wind is a turbulent magnetofluid. Intense fluctuations occur on a wide range of scales extending over several orders of magnitude. Clear evidence has been found in the data for intermittency and non-Gaussian statistics. To analyse these features the scaling properties of the fluctuations and their structure functions have been investigated in detail. Spacecraft observations show that the structure functions of the solar wind velocity and magnetic field, and of the proton density and temperature have scaling properties consistent with an intermittent behaviour. This is most obvious in the probability distributions, which reveal strong deviations from a Gaussian and indicate small-scale coherent dynamics. The turbulent kinetic energy flux shows multifractal scaling, which can be expressed and quantified in terms of its multifractal spectrum. Various theoretical concepts and models have been developed to explain the solar wind observations by invoking a fractal and scale-dependent energy cascade. A tutorial presentation of some of the models is given, and detailed comparisons of the data with the theories are presented.

MULTISCALE STRUCTURE OF THE INTERPLANETARY MAGNETIC FIELD: FRACTON EXCITATIONS AND THE POWER-LAW SPECTRA

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We study the statistics of the magnetosonic waves on the clusters of the IMF whose geometry is approximated by a fractal. Our prime interest concentrates on the role of these waves in formation of the power spectra of the IMF fluctuations in the corresponding frequency ranges. We argue that the magnetosonic waves on the fractal clusters of the IMF could be considered as a specific type of quasiacoustic excitations termed fractons (*Alexander and Orbach*, 1982) having an "unconventional" dispersion law depending on the topological properties of the fractal cluster. In this context, we propose a formalism which involves an investigation of the connectivity of the fractal sets. We propose an unconventional type of wave equation with the *fractional* time derivative, which generalizes the standard wave equation for the fractal geometries. We prove that the order of the time differentiation in this equation depends explicitly on the so-called index of connectivity of the fractal cluster. We found an analytical solution to the generalized wave equation on fractals, enabling one to calculate directly the power spectra of the IMF turbulence. Our results show a good agreement with the direct spacecraft measurements of the IMF turbulence in a wide range of frequences and heliocentric distances.

SINGULAR SYSTEM ANALYSIS OF THE SOLAR WIND

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The solar wind data, especially in the low-speed stream with irregular fluctuations of velocities, is a good candidate to apply the methods of nonlinear analysis. In the embedding space, constructed due to the Takens theorem, the singular analysis allows us to recognize the directions that are most frequently visited by the trajectory and by reducing the noise to estimate the dimension of the reconstructed space. The embedding space is represented by a complete set of orthogonal functions and is obtained from a numerical analysis of the data. The number of directions necessary for the complete reproduction of the nonlinear dynamic of the system should be large enough; otherwise the dimension of the subspace to which all the trajectories asymptotically approach could be underestimated. The obtained results were subjected to statistical tests for determinism and the results were significantly different than those obtained from the original data. Thus we can expect that the inner heliosphere is a nonlinear possibly chaotic system, at least in a submanifold of the phase space.

EXACT SCALING LAWS FOR TURBULENT MHD FLOWS

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Turbulent flows produce strong, sparse, localized structures which may give rise to anomalous exponents for the self-similar scaling of two-point structure functions of the physical fields. Such intermittency is constrained by exact laws stemming from the conservation properties of the dynamical equations, and is documented for the Solar Wind by several observations. In the case of laboratory experiments on neutral fluids, a better fit to the data obtains when, using Extended Self-Similarity (or ESS), one takes as the dependent variable (as contrasted with direct scaling with the distance r between the two points), the third-order correlators that are proportional to r. Such correlators can be viewed as "dynamical length scales" ℓ_{YS} that directly arise from the Navier-Stokes equations in the wake of the analyses of von Kármán and Howarth, of Kolmogorov as well as that of Yaglom.
The equivalent laws have been obtained in MHD for any amount of velocity-magnetic field correlation and for an homogeneous, isotropic and incompressible fluid. They lead to new dynamical lengths ℓ_{MHD}, and will be derived here explicitly in a simplified case. We thus suggest an ESS hypothesis for MHD that makes use of two sets of third-order *cross*-correlators written in terms of correlation or structure functions and involving *both* the velocity and the magnetic field. These *new* dynamical lengths are more appropriate candidates than ℓ_{YS} in the reduction of Solar Wind data, since they appear as fundamental correlators stemming from the non-linear dynamics of conducting flows.

A NUMERICAL STUDY OF THE CORRELATION BETWEEN DENSITY AND TEMPERATURE FLUCTUATIONS OBSERVED IN SOLAR WIND

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We compare the results of our numerical simulations with the analysis of the correlations between density and temperature fluctuations obtained from Helios 2 and Isee data. In our model, a spectrum of Alfven waves propagates across a spatially inhomogeneous magnetic field embedded in a plasma with a non uniform entropy distribution, that should modelize a magnetic sector boundary in the Solar Wind. We found that the interaction between the non compressive (Alfven) waves and the inhomogeneous structure produces compressive waves of two types: fast and slow magnetosonic waves, with a positive correlation between density and temperature, and static entropy waves. We found that, by going toward the smaller scales, the density-temperature correlation becomes more positive in the zone where the magnetic field is homogeneous, while it is negative in the inhomogeneous zone. That seems to be an indication of the fact that the static entropy waves are concentrated only in proximity of the inhomogeneity, where they are produced, whilst the magnetosonic waves propagate away, by filling the homogeneous zone as well. Analogous trend is got from the analysis of the data.

TERMINATION SHOCK EXCURSIONS: POSSIBILITIES FOR VOYAGER ENCOUNTER

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Fluctuations in the solar wind upstream of the termination shock as well as in the LIC plasma will cause inward and outward motions of the shock. In the paper we discuss various scenarios for the interaction between solar wind and interstellar matter including an influence of the local interstellar magnetic field on the heliospheric boundary configuration and a presence of interstellar neutral hydrogen.

ION INJECTION, ACCELERATION, AND WAVE GENERATION AT THE QUASI-PARALLEL BOW SHOCK

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The processes of particle injection and acceleration and of upstream wave generation at quasi-parallel collisionless shocks are intimately connected and highly non-linear processes. The upstream waves are convected downstream by the plasma flow and are ultimately responsible for the shock dissipation. We have investigated the coupled process of particle injection/acceleration, wave generation, and downstream dissipation at quasi-parallel shocks by hybrid simulations, which treat the ions as macroparticles and the electrons as a massless fluid. Solar wind alpha particles are included self-consistently in order to make predictions as to the dependence of the injection rate on species and differences in upstream diffuse alpha particle spectra versus proton spectra. We will show that a large fraction of both protons and alpha particles are already accelerated at the shock before they leave the shock for the first time in the upstream direction. These ions are trapped near the shock ramp and are accelerated by the upstream wave electric field. We compare the simulations with a recent simplified model by Malkov (1997) for the ion injection at quasi-parallel shocks.

ENTROPY OF THE SOLAR WIND FLOW IN THE INNER HELIOSPHERE

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We analyse a time series of velocity fluctuations of the low-speed stream of the solar wind measured by the Helios spacecraft in the inner heliosphere. We estimate the *Kolmogorov* entropy directly from the signal and show that the entropy is finite and positive, which is an indication for a chaotic behaviour of this complex system. These results supported our previous suggestion that trajectories describing the system in the inertial manifold of phase space can asymptotically approach the attractor of a low-dimension. Furthermore, the obtained characteristics of the attractor are significantly different from that of the surrogate data. Thus the results of these tests suggest that the inner heliosphere is *nonlinear* deterministic and possibly chaotic system, at least in the inertial manifold of the phase space.

PROBABILITY DISTRIBUTION FUNCTIONS OF TURBULENT FLUCTUATIONS IN THE SOLAR WIND

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The probability distribution functions (PDF) of the velocity and magnetic field gradients in the solar wind have been analyzed using the Helios II spacecraft data collected in the inner heliosphere. We consider two different data sets, one including the slow-wind periods and the other one including the fast-wind periods. The PDFs have been fitted with a theoretical function representing a convolution between gaussian PDFs with variance distributed according to a log-normal function. The resulting PDF depends on a single parameter λ, which characterizes the intermittency of the signal, and we studied the scaling behavior of λ vs. the time-scale τ. We found that $\lambda \sim \tau^{-\beta}$, but two distinct values for β are present, at least in the slow-wind. No differences appear between velocity and magnetic field fluctuations.

SMALL ELECTROSTATIC POTENTIAL DROPS IN THE SOLAR WIND

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The TDS experiment on Wind detects electrostatic waveforms in the solar wind with a high temporal resolution. Weak double layers, lasting about 1 millisecond, are observed in the solar wind, except in the overdense heliospheric plasma sheet. In these weak double layers, the electrostatic potential generally drops antisunward: it varies in the same sense as the interplanetary potential which accelerates the solar wind protons. We discuss the occurrence and the amplitude of these small (3 to 20 mV) potential drops in relation with the direction of the magnetic field, the gradient of the electron thermal energy and the variations of the electron heat flux.

SELF-SIMILARITY CONCEPTS FOR GEOMAGNETIC PULSATIONS

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Recent analysis has shown that low frequency geomagnetic fluctuations exhibit the same kind of scaling symmetry as MHD turbulent flows in the solar wind. In this paper we analyse geomagnetic fluctuations on the time scale of geomagnetic pulsations. We use the data from two station pairs in Central Europe and in Colorado, USA. First, we identify pulsations which characteristics are controlled by the solar wind and separate the frequences of others which are controlled by resonances (eigenmodes) of individual field lines. To this end we use gradient methods and continuously compute cross power spectral density and cross phase dynamic spectra. After the separation of quasi-periodic (field line resonance) and broad-band components we apply the methodology of extended self-similarity to study scalings. The aim of this study is to understand better the position of the geomagnetic pulsations in a complex energy cascade with the driving energy source arising from the non-local interaction between the solar wind and the magnetosphere.

PROPERTIES OF THE SOLAR WIND TURBULENCE AS REVEALED BY THE WAVELET TRANSFORM

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Solar wind turbulence is highly nonhomogenous, exhibiting well localized jumps, spikes and discontinuities. These coherent structures are apparently caused by nonlinear processes and play an important role in the dynamics of turbulent plasma. The usefulness of the wavelet transform in studying turbulence stems from the fact that it can be performed locally, preserving the information about local features of the turbulence. We show that the high-frequency ($\geq$0.01 mHz) local wavelet spectra of the Elsässer variables of the low-speed solar wind at 0.3 AU are highly variable along the Helios 1 orbit. Application of the wavelet-based nonlinear filtering allowed us to separate coherent structures from the noise-like, Gaussian background. Spectral indices of the Elsässer variable Z+ are approximately -2 and -1 for the coherent and noise-like components, respectively. Flatness of the wavelet coefficients show that the outward propagating perturbations are non-Gaussian at scales less than 30 minutes, while the inward perturbations become non-Gaussian at time scales less than 1 hour, confirming the earlier results.

NP2 Predictability & time series analysis

01 Quantifying predictability

Convener: Toth, Z.

ON THE RELATIONSHIP BETWEEN SINGULAR VECTORS AND BREEDING MODES, A COMPARATIVE STUDY WITH A SIMPLE MODEL.

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Two different methods to study error evolution patterns in atmospheric models have been intercompared. The two methods are *singular vectors* and *breeding*. We use a forced and dissipative, spherical, baroclinic, two-layer, quasi-geostrophic model with a T21 truncation. The comparison is based on properties such as baroclinicity, heat transport, growth rate and spatial structures. We find that the spatial structure of the modes are very similar in both methods. The energy cascade which takes place in the non-linear model integrations goes towards the synoptic scales at optimization time in both cases. The baroclinicity is well pronounced for both methods but at different evolution times. We conclude that both methods give the same kind of information about the most unstable "phase-space" directions for a simple model. A major part of the observed differences between the two methods appears to depend on differences in models and fields used to initialize the modes instead of differences in the formulation of the methods.

ENSEMBLE FORECASTING OF HURRICANE TRACKS AND INTENSITY

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The National Centers for Environmental Prediction (NCEP) have been operationally running their suite of global forecast models by creating ensembles of initial conditions based upon breeding of the most rapidly growing modes in the model. During the 1996 and 1997 Atlantic and East Pacific hurricane seasons, eleven member ensembles of a low-resolution version of the operational Geophysical Fluid Dynamics Laboratory (GFDL) hurricane model were run on a relatively large number of tropical cyclone cases based upon the NCEP bred growing modes. The ensembles can be used to determine the confidence forecasters may have in individual forecasts, and to improve the forecasts themselves. The 72 h forecasts from individual ensemble members are verified along with ensemble mean forecasts. The skill of the low- resolution ensemble forecasts is compared with that of the high-resolution operational GFDL model forecasts, and the relationship between forecast spread and forecast errors are shown. The ability of the ensemble forecasts to envelop the true storm trajectories is examined.

IMPACT OF ENSEMBLE SIZE ON ENSEMBLE PREDICTION

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The impact of ensemble size on the performance of the European Centre for Medium-Range, Weather Forecasts (ECMWF) Ensemble Prediction System (EPS) is analyzed. The skill of ensembles generated using 2, 4, 8, 16 and 32 perturbed ensemble members are compared for a period of 45 days, from 1 October to 15 November 1996. For each ensemble configuration, the skill is compared with the potential skill, measured by randomly choosing one of the 32 ensemble members as verification (idealized ensemble). Results are based on the analyzes of the prediction of the 500 hPa geopotential height field. Various measures of performance are applied: skill of the ensemble mean, spread-skill relationship, skill of most accurate ensemble member, Brier score, Ranked Probability Score, Relative Operating Characteristic, and the Outlier Statistic. The relation between ensemble spread and control error is studied using L2, L8, and Lý norms to measure distances between ensemble members and the control forecast or the verification. It is argued that the supremum norm is a more suitable measure of distance, given the strategy for constructing ensemble perturbations from rapidly-growing singular vectors. Results indicate that, for the supremum norm, any increase of ensemble size within the range considered in this paper is strongly beneficial. With the smaller ensemble sizes, ensemble spread does not provide a reliable bound on control error in many cases. By contrast, with 32 members, spread provides a bound on control error in nearly all cases. It could be anticipated that further improvement could be achieved with higher ensemble size still. On the other hand, spread skill relationship was not consistently improved with higher ensemble size using the L2 norm. The overall conclusion is that the extent to which an increase of ensemble size (particularly from 8 to 16, and 16 to 32 members) improves EPS performance, is strongly dependent on the measure used to assess performance. In addition to the spread/skill relationship, the measures which are most sensitive to ensemble size are shown to be the skill of the best ensemble member (particularly when evaluated on a point-wise basis), and the Outlier Statistic.

TARGETING OBSERVATIONS TO IMPROVE TROPICAL CYCLONE TRACK FORECASTS

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During the past two decades, improvements in tropical cyclone track forecasts have averaged only about 1% per year. Since 1982, the Hurricane Research Division of the National Oceanographic and Atmospheric Administration (USA) has conducted twenty-five "Synoptic-Flow" experiments in data-spare oceanic regions roughly 48 - 72 h before projected landfall of a mature hurricane. Vertical profiles of wind, temperature, and humidity within 1000 km of the center of the tropical cyclone were gathered from sondes dropped from research aircraft. The dropwindsonde data produce significant (16% to 30%) improvements in operational two to three day track forecasts. Although the general observing strategy of relatively uniform data coverage is capable of this substantial forecast improvement, due to limited aircraft range. an optimal deployment strategy must be developed to obtain the greatest improvements in the forecasts. Areas where small perturbations to the model initial condition are likely to grow most rapidly are identified using operational ensembles derived from the National Centers for Environmental Prediction (USA) Medium-Range Forecasts Model. Using different configurations of the dropwindsonde data in seven available cases, an optimum observation strategy is presented.

LOW-FREQUENCY VARIABILITY OF THE ATMOSPHERE AND LONG-RANGE FORECASTING

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Atmospheric low-frequency variability (LFV) spans the time scale between 10 and 100 days, longer than synoptic-scale eddy formation-and-overturning time and shorter than duration of the year's extreme seasons, winter and summer. LFV can be described in terms of persistent anomalies of the midlatitude circulation, such as blocking events, and in terms of intraseasonal oscillations, such as the tropical 50-day and the extratropical 25-, 40- and 70-day oscillations. These two descriptions, intermittent and oscillatory, have given rise to two kinds of statistical long-range forecasting (LRF) schemes, based on Markov chains and the singular-spectrum analysis (SSA) / maximum-entropy method (MEM), respectively. We shall discuss the relationship between the two descriptions and hence the two approaches to LRF, from the point of view of the detection and predictability of spatio-temporal patters. Hybrid forecasting based on a dynamic model's assimilating statistical predictions will also be outlined.

NP2

FLOW DPENDENT PARAMETRIZATION OF TENDENCY ERROR ON A SIMPLIFIED MODEL

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An extremely simplified general circulation model has been built with the aim of modeling the large scale atmospheric flow. The model used is a Quasi Geostrophic three levels model. A control run has been performed making use of a forcing term obtained as an average model residual or model tendency error. Consequently, a flow-dependent parametrization is sought for, making use of the analogues technique to establish the relation between flow and model residual. Different way to compute the model residual are tested, such as direct calculation or variational optimization making use of the adjoint model. An improvement of the model climatology and variability is found and commented.

GLOBAL CLIMATE SIGNALS AND THE SPANISH RAINFALL

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Abstract: In this work we try to establish a connection between some global climatic signals, and some other of regional interest for the Iberian Peninsula, such as the anomalous precipitation. In particular we explore the relationship between the latitudinal position of the north-hemisphere polar Jet Stream and a major climate signal like ENSO and also with the North Atlantic Oscillation. Through the correlation between these global signals and the Spanish Station rainfall records we separate different regions of influence in the Iberian Peninsula. A forcast scheme, where the same anomalous rainfall time-series are used as predictors, is also discussed.

Quantifying predictability with Lyapunov exponents

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The Lyapunov exponents of a system describe the rate at which nearby trajectories on an attractor separate. Thus, the largest Lyapunov exponent, λ_1, quantifies the inherent predictability in a time series. There are several methods for calculating the Lyapunov exponents directly from the data. Using a technique first described by Eckmann and Ruelle, then improved by Abarbanel, et. al., the prediction horizons for ocean water levels at a variety of tide stations are derived. The prediction horizon is arbitrarily defined as the aggregate point where the trajectories separate to 1/2 of the mean attractors size (although any criteria can be used). For the stations examined, the prediction horizon varied from over 10 hours for stations well exposed to the open ocean to about an hour for a station well inside a complex estuary. Large numbers of predictions made using a phase space method invented by Abarbanel, et. al. had average error growth rates consistent with the computed value for the largest Lyapunov exponent. This study demonstrates the feasibility of using λ_1 for classifying the dynamics of ocean water levels and accurately estimating the limits of prediction. Temporal variations of λ_1 show how predictability varies with time.

PREDICTABILITY OF THE NORTH ATLANTIC ANOMALOUS CIRCULATION

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Abstract: We attempt to develop a predictive scheme for the atmospheric circulation over the North Atlantic basin with statistical tools like multivariate lagged regression and singular value decomposition procedures. We have used as predictands the principal components of the 850hPa air temperature in the frecuency band related to the stormtracks and as predictors the principal components of the SST and the ones of the very same air temperature field. The period of time analized in this study covers from 1968 to 1996, and both hindcast for all the period and forecast in the last 6 years have been computed. The atmospheric data comes from the Reanalysis of NCEP, and the ocean data is a blend of COADS and IGOSS data sets.

HYBRID DYNAMIC-STATISTICAL FORECASTING AND FORECAST SKILL

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We study hybrid forecasts that combine dynamical predictions based on a numerical model and statistical predictions based on past observations of the system. Vautard et al. (*Physica D*, 1992) suggested this approach for the prediction of low-frequency variability in the coupled ocean-atmosphere; it also holds promise for extending atmospheric predictability (Strong. Ph.D. thesis. UCLA, 1994; Pires, Ph.D. thesis, Paris-VI, 1995). To combine the dynamical and statistical components of the forecast system efficiently, we use sequential estimation theory (Kalman filtering) for nonlinear systems. In the present study the methodology is applied to a highly idealized coupled ocean-atmosphere model (Molteni et al., *J. Climate*, 1993; Ghil and Jiang, *GRL*, 1998) allowing us to conduct an analytical study that provides fundamental insight into hybrid forecasting. The impact of ensemble forecasts performed in one or both of the two components is examined so as to extend the forecast skill by capturing the onset of major transitions and warm or cold events. Predictors of forecast skill for this hybrid approach are also developed. The future application to more realistic – and ultimately operational – forecast systems is also discussed.

NONLINEAR PREDICTORS FOR IONOSPHERIC DATA

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Time series of the observably of reflected HF radio wave, obtained by digital ionosonde are examined. We applied well-known algorithms available for the calculation of geometric and dynamical invariants of an underlying dynamical system. When we deduced, that our time-series is deterministic, we used numerical techniques for constructing nonlinear predictive model directly from time series. We constructed pieswise short-term predictor and predictor using so-called radial basis technique. Radial basis predictors seemed superior to pieswise predictors. Using direct pieswise predictor we were able for the embedding dimension np= 8 to predict with normalized predictor error E= 0 for T= 7 samples ahead. Results of iterative predictions were superior: for the same embedding dimension np=8, E= 0 for T= 70. If we'll change the value of tau (tau is a time delay), then for np= 20, tau=8 it allows to predict with E= 0 for T= 19, that is the common prediction time T= 162.

ON CALCULATION OF THE PROBABILITY DISTRIBUTION FUNCTIONS FOR STATISTICAL ENSEMBLES WITH THE LARGE NUMBERS OF FREEDOM DEGREES.

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The special iterative procedure for the calculating the ensemble probability distribution function has been suggested when this function satisfies the Fokker–Plank type equation or the averaging Liouville equation which can be reduced to a system of parabolic equations.
The developed approach is based on adapting the method of small parameter suggested by *Dorodnitsin* [1973] for numerically solving differential equations. The method was generalized for the solving n–dimensional linear parabolic equations in *Ivanov and Margolina* [1997], *Ivanov and Margolina* [1998], who demonstrated, that iterative procedure linearity converges and found the conditions of this convergence.
Our experience shown that 1. The probability distribution functions calculated by our method is essentially different from the Gaussian distribution functions used usually in n–dimensional cases. 2. Our approach is more effective, than the Monte–Carlo technique when all other conditions are equal. The general theory is illustrated by the estimating the time of predictability for the Black Sea low–frequency circulation. The horizon of predictability for the nonlinear three–dimensional prediction model based on primitive hydrodynamical equations (*Eremeev et al.* [1992]) is also found.

QUANTITATIVE PRECIPITATION FORECASTING: PREDICTABILITY LIMITS AND THE USE OF ENSEMBLE FORECASTS

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Precipitation forecasts lose skill more rapidly than forecasts of any other surface weather element. Therefore, it is critically important to document the predictive limits for precipitation and to examine how ensemble forecasting can improve the reliability of quantitative precipitation forecasts (QPFs). These issues are addressed in this talk, which describes results from an analysis of 90 ensemble forecasts with 15-members from limited-area models with 80 km grid spacing. Rapid error growth characterizes precipitation. Predictability limits for 6-hour accumulations at the model grid points can be as short as 12 to 24 hours. Our results suggest that ensemble techniques can improve the reliability of QPFs, but improvements may be minimal without statistical post-processing of the raw output

STRATOSPHERIC PREDICTABILITY IN THE UKMO UNIFIED MODEL

W. A. Lahoz (CGAM, University of Reading RG6 6BB, UK)

The predictive skill of the UKMO Unified Model (UM) in the stratosphere is studied by applying conventional verification statistics used in Numerical Weather Prediction (NWP). The impact of model resolution and the location of the model lid on the lower stratosphere predictability in the wintertime is studied for short-term deterministic forecasts; special reference will be made to southern hemisphere winter-spring and northern hemisphere winter. Differences between the predictability of the lower stratosphere and the mid troposphere are highlighted and explained in terms of the flow regimes prevalent in these regions. The impact of the stratosphere on tropospheric predictability is studied for short-term deterministic forecasts and for seasonal ensemble forecasts.

A BAYESIAN APPROACH TO RAINFALL DISAGGREGATION

Christian Onof, Neil Mackay, Richard E. Chandler, Howard S. Wheater (Imperial College, London, UK)

Rainfall forecasts generated by mesoscale models have to be downscaled for use in hydrology. This may be accomplished by combining coarse scale forecasting with some persistence assumption at the fine scale. We here propose an approach which explicitly uses a dependence upon the previous time-step to disaggregate coarse scale rainfall fields and is stochastic so as to allow for the simulation of a range of possible small scale scenarios, thus providing an estimate of uncertainty.
The wet/dry problem is considered separately from that of the rainfall intensities. For the first, we use an analogy between image processing and disaggregation. In this Bayesian scheme, evidence constituted by the disaggregated field at the previous time-step and the coarse scale intensities are both incorporated to update the prior information which is given by a Markov Random Field structure, so as to obtain the posterior distribution from which the selected field is constructed.
For the rainfall intensities, a simple scheme is developed, based upon the gamma distribution and the observed morphology of wet areas.
The results show that the simulated wet/dry field is not distinguishable from the observed field in terms of the number of correctly classified pixels, and coverage for data sets from Arkansas (USA) and Wardon Hill (UK), while the intensity distribution is visually adequate although more quantitative testing is required here.

EVALUATION OF THE STABILITY OF ALGORITHM CN WITH RESPECT TO RANDOM ERRORS IN MAGNITUDE: CENTRAL ITALY

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Since all the catalogue of earthquakes are inevitably affected by errors. we established to analyse how random errors on magnitudes may influence the results of earthquake prediction with algorithm CN, essentially based on a robust analysis of the seismic flow. For this purpose, CN has been applied to the region currently used for the monitoring of seismicity in Central Italy. using several randomised catalogues. The magnitudes given in the original catalogue CCI1997 have been changed randomly, according to a normal distribution centered on the original magnitude and with standard deviation 1/3ME (Maximum Error). ME varying from 0.1 and 0.5 have been considered. Results obtained with ME=0.3 appear satisfactory, because all the three strong earthquakes are predicted with a percentage of TIPs (Times of Increased Probability) that is greater than that obtained with the original catalogue. but still comparable with the global results. This seems to indicate that possible errors of such kind don't compromise substantially the predictive power of the algorithm. Nevertheless. it has been observed that with ME greater than 3.0 there is a failure to predict and the number of false alarms increases remakably.

PREDICTABILITY, LYAPUNOV VECTORS AND WEATHER REGIMES IN A T21L3 QUASI-GEOSTROPHIC MODEL

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The spatial distributions of the Lyapunov vectors of a T21L3 quasi-geostrophic model are investigated with special emphasis on their relation with the weather regimes generated by the model. A clustering procedure of the anomaly weather fields based on the local amplification rate of the dominant Lyapunov vector is performed. It is shown that large and small amplification rates are associated to distinct flow fields which present strong similarities with two weather regimes of the model, suggesting that these regimes display different predictability properties.

EVALUATION OF PROBABILISTIC PREDICTION SYSTEMS

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Ensemble Prediction Systems (EPS's) are particular cases of Probabilistic Prediction Systems (PPS's), *i. e.* systems that predict a probability distribution for the state of the atmospheric flow. The value of a Probabilistic Prediction System lies in the conjunction of two independent qualities, namely *reliability*, *i. e.* the quality that the *a posteriori* observations are statistically consistent with the *a priori* predicted probability distributions, and *resolution*, *i. e.* variability in the predicted probability distributions. A number of scores commonly used for evaluating the quality of EPS's are discussed in terms of which of these two qualities they measure. In particular, the classical Brier score can be decomposed into the sum of two terms which independently measure reliability and resolution (Murphy, 1973, *J. Appl. Meteor.*, **12**, 595-600).
The impact of the finiteness N of forecast ensembles on various scores is discussed. The Brier score is degraded by an additive term proportional to $1/N$, which shows rapid saturation of the score with increasing N.
The reliability and resolution of the ECMWF and NCEP EPS's are evaluated at various forecast ranges. The performance of both systems is also compared with the performance of an economical 'poor man's EPS' which, being based on a search for past analogues, does not require explicit integration of the forecasting model from 'perturbed' initial conditions.

NP2 Predictability & time series analysis

02 Execution and analysis of geophysical laboratory experiments

Convener: Malinowski, S.P.
Co-Convener: Früh, W.-G.

PROPERTIES OF THE TURBULENT CLOUD-CLEAR AIR INTERFACE OBSERVED IN THE LABORATORY EXPERIMENT.

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Abstract

A cloud-clear air mixing is observed in the laboratory experiment with use of a laser sheet technique. The vertical and horizontal sections through the mixing volume are imaged in the range of scales from 1 mm to 1m. On the images an interface separating cloudy and clear air filaments is determined in order to investigate its scaling properties. Results indicate anisotropy with the preferred vertical direction and scaling from about 2cm up. Based on these results a new estimates of surface of an interface separating cloudy and clear air is proposed.

THE EFFECT OF SLOPING BOUNDARIES ON BAROCLINIC INSTABILITY IN TWO RELATED INTERNALLY HEATED, ROTATING FLUID SYSTEMS.

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Results have been obtained from two internally heated, rotating fluid systems, with differing aspect ratios, in which a β-effect (variation in Coriolis parameter with latitude) has been simulated by the inclusion of oppositely sloping endwalls. The boundaries are arranged so that the fluid depth (D) can either increase with radius ($\partial D/\partial r > 0$) or decrease with radius ($\partial D/\partial r < 0$). In both systems stable eddy features are observed over a wide range of rotation rates (Ω) for each endwall arrangement. However, while a large number of different azimuthal wavenumber (m) modes are seen in the regular wave regime of the $\partial D/\partial r > 0$ endwall experiments, only the gravest mode ($m = 1$) is seen in the regular wave regime of the $\partial D/\partial r < 0$ endwall experiments. Within the former experimental arrangement the radial scale of the eddy features are found to be approximately that of the Rhines scale $L_3 = \pi\sqrt{2U/\beta}$, while in the $\partial D/\partial r < 0$ endwall experiments the eddy kinetic energy is seen to penetrate the L_3 scale and accumulate at the largest domain-filling scales. This remarkable difference in the flow structure of the two endwall arrangements (which is not related to the geometry of the convection chamber) may find a partial explanation in terms of established results on the instability of finite amplitude barotropic Rossby waves, with $\partial D/\partial r < 0$ endwalls removing the stability thresholds on wave amplitudes for all but the gravest mode.

INVESTIGATION OF THE DROPLET CONCENTRATION AT THE CLOUD-CLEAR AIR INTERFACE.

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Abstract

A cloud-clear air mixing is observed in the laboratory experiment with use of a laser sheet technique. Analysis of the intensity of the scattered light on the images from the experiment is used in order to veryfy the hypothesis on the increase of droplet concentration at the interface. Since droplet terminal velocity is a function of the droplet radius, possible partial evaporation of droplets at the interface may lead to formation of the accumulation zone. First results from the experiment indicate a dependence of the thickness of the interface on its orientation, supporting the hypothesis on increase of the concentration.

MESOSCALE DATA ASSIMILATION OF SURFACE UND UPPER AIR OBSERVATIONS IN INTENSE PRECIPITATION EVENTS.

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We devised an analysis scheme which makes use of observed surface data, combined with upper air radionsounding observations, to build vertical profiles of wind, humidity and geopotential over surface observing stations. The reconstructed vertical profiles are analysed on constant pressure levels and at surface through a successive correction method by means of ECMWF analyses as background fields. We recently improved the scheme of vertical adjustment of surface quantities within the PBL and we are planning to introduce an horizontal initialisation procedure for wind and mass fields and to include satellite observations in the scheme in order to build upper troposphere humidity profiles. The analysed fields, computed every 6 hours, are assimilated into our operational limited area model (LAMBO, based on a version of NCEP ETA model) during a 12 hour pre-forecast period through Newtonian nudging of prognostic variables. The model is then run with ECMWF fields (forecast or analysed) as boundary conditions. We successfully tested our data assimilation scheme over various intense precipitation events in the Alps and Mediterranean region, such as Versilia (June 19 1996), Piedmont (November 5-6 1994) and South Ticino (September 13 1995) floods.

ROUTES INTO CHAOS IN ROTATING FLUIDS

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Abstract. We report on a concurrent study on stability, bifurcation scenarios and routes into chaos in rotating fluids, i.e. Taylor Couette flow and spherical Couette flow. In contrast to the pitchfork bifurcation as the first instability in the cylindrical system the flow in the spherical gap flow bifurcates via different Hopf bifurcations into chaos. By increasing the Reynolds number with the angular velocity of the driving inner sphere the flow bifurcates from laminar axisymmetric basic flow to the periodic motion of non-axisymmetric spiral waves for relative large aspect ratios. The spiral waves exist over a wide range of the Reynolds number. In this range a change in shape and periodicity can be detected by visualization with small aluminium flakes and also measured by Laser Doppler velocimetry (LDV-technique). At high Reynolds numbers, the flow undergoes a bifurcation to low-dimensional chaotic motion before it becomes turbulent. The dynamic behaviour of the rotating flows mentioned above is compared and discussed by time series analysis methods and by velocity and frequency bifurcation diagrams.

INERTIA-GRAVITY WAVES IN A BAROCLINICALLY UNSTABLE ROTATING FLUID

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It is increasingly recognised that time-varying large-scale geostrophically balanced flow in the atmosphere and oceans may be accompanied by the excitation of fast inertia-gravity waves as a form of 'geostrophic adjustment'. This has lead to controversial suggestions that the perturbations associated with these waves may lead to the disruption of the 'slow manifold', which forms the conceptual basis of many operational techniques for initialising weather forecasting models. In the present work, a novel optical technique has been used to visualise and measure a baroclinically unstable flow in a two-layer rotating annulus experiment in the laboratory. Small-scale, high frequency inertia-gravity waves were detected in association with a baroclinic wave undergoing periodic amplitude vacillation. The observations of these phenomena will be discussed, together with their quantitative analysis as inertia-gravity oscillations, and experimental evidence will be presented which suggests that a slow 'quasi-manifold' survives the onset of these fast wave motions. Results will be further discussed in the context of the geostrophic adjustment problem.

FLOW-FIELD AND POINT VELOCITY MEASUREMENTS IN A BAROTROPICALLY UNSTABLE SHEAR LAYER.

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Abstract

We present laboratory experiments on a classic fluid instability in rotating fluids whose treatment dates back to Stewartson (1957). It is the stability of a region of strong shear in a barotropic rotating fluid, where the shear layer is forced by imposing a differential rotation of the upper and lower horizontal boundaries of a cylindrical tank. Such shear layers occur in the late stages of the evolution of mid-latitude weather systems and of tornadoes, as well as within the liquid Earth's core or across the banded structure of the Giant planets.

The experiments have investigated the flow structures arising from the instability by using two measurement techniques; (1) particle tracking velocimetry to measure the horizontal flow field globally, and (2) long time series of very accurate single-point velocity measurements using Laser Doppler velocimetry. The relative merit of the two techniques will be discussed. The equilibration of the flow to steady vortex waves, not unlike the string of vortical structures observed in Jupiter's atmosphere along latitude circles, will be presented. The development of complex time-dependent behaviour of the vortices and the break-down of barotropic solutions by the emergence of three-dimensional flow structures will be discussed.

KELVIN-HELMHOLTZ INSTABILITY IN A CONTINUOUSLY FORCED SHEAR FLOW.

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Abstract

Kelvin-Helmholtz instability is a frequently observed fluid instability in atmospheric and astrophysical situations. In the atmosphere for instance, the occurrence of clear-air turbulence is frequently attributed to this instability. Previous experiments were mainly conducted in a tilting closed tube or in open-flow experiments. We present a study of Kelvin-Helmholtz instability in a closed annular two-layer experiment where the shear across the layers is maintained at a steady rate by rotating the lid in contact with the upper fluid at a constant speed.

The flow is measured by global mappings of the interface height which can be estimated from the distortion of a reference grid by refraction at the interface due to mismatch in the refractive indices of the two fluid layers. This method is applied to both immiscible layers of silicone fluid and water, and to miscible layers of fresh water and salt water. The initial instability of the fluid interface and the wave number of the emerging flow will be compared with linear stability calculations.

DYNAMIC STATE-SPACE RECONSTRUCTIONS: A CASE STUDY WITH A THERMALLY DRIVEN, ROTATING FLUID ANNULUS

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The thermally driven, rotating fluid annulus provides spatial-temporal data for a wide variety of flow conditions, each with various geophysical analogues. Through the analysis of data from this experiment, various aspects of nonlinear reconstruction techniques are illustrated. The information content of time series from a single probe is contrasted with that of data sets of multiple measurements. Noise reduction techniques are contrasted, and compared using the same data set. Several aspects of ensemble forecasting are investigated, including ensemble formation, verification, and the use of ensembles over different models. Finally, the extent to which data based nonlinear models can contribute to "understanding the physics" of physical systems is contrasted with the contribution available from first principles simulations.

LDV-MEASUREMENTS ON BAROCLINIC WAVES

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Abstract. We report on laboratory experiments of baroclinic instabilities in the rotating annulus cooled from within. The flow undergoes different transitions from the laminar basic state through various stages of instability to an irregular state. LDV-measurements of the radial velocity component were carried out to describe the instabilities, the bifurcation scenario and the route into chaos. The LDV-time series at different positions in the rotating annulus are analysed with classical linear tools like autocorrelation functions and fourier spectra and also with modern tools of non-linear dynamics applied on a reconstructed phase space.

POD ANALYSIS OF BAROCLINIC WAVE FLOWS IN THE THERMAL ROTATING ANNULUS EXPERIMENT.

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Abstract

The Proper Orthogonal Decomposition (POD) is a procedure to compute an orthogonal basis from a time series of spatial fields. This basis is optimal among all linear decompositions, in the sense that for a given number of modes, the projection of the original signal onto the subspace will contain the most variance on average. This algorithm is applied to streamfunction fields derived from measurements of the flow in the thermally forced rotating annulus experiment. Results of this analysis are presented, and a method to derive low-dimensional models of the flow by projecting the equations of motion onto these empirical eigenfunctions is discussed.

NP2 Predictability & time series analysis

03 Nonlinear time series analysis

Convener: Kurths, J.
Co-Convener: Yiou, P.

IS THERE MEMORY IN SOLAR ACTIVITY?

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The Hurst effect is a presumed and unexpected behaviour of geophysical time series (tree ring indices, varve thicknesses, precipitation and streamflow records, etc.) by which these time series have persistence or "memory". In a thorough study about the presence of the Hurst effect in geophysical time series, Mandelbrot and Wallis analyzed monthly sunspot numbers and obtained $H = 0.86 \pm 0.05$, suggesting that solar activity shows persistence and that the underlying responsible mechanism can guarantee a positive correlation of solar activity during long time lapses. Here, we have followed the scale of fluctuation approach to show that there is no incontrovertible evidence for the presence of the Hurst effect in sunspot areas and, therefore, that there is no long-term memory in solar activity.

OBJECTIVE SPECTRAL METHOD APPLIED TO METEOROLOGICAL SERIES

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Study techniques of temporary series of meteorological variables, guided to spectral analysis have been centered on the transformed classic Fourier (FT) and on the maximum entropy spectral analysis method (MESA). However, for the nature of the signal, the results are quite not conclusive and in many occasions they are not more than mere conjectures of the real meaning of the spectra maxima. Therefore is a methodological exigency to find a capable objective technique able to discriminate those spectral maximums obtained as a result of the information of the signal, from those that are fruit of the use of mathematical devices. This study carry out about meteorological series of variable temporary order, show the application of the techniques based on the temporary evolution of the spectrum (MSA) and presents the evaluation of the real meaning level (TSR) of the spectra maxima, therefore objective conclusions of the information is obtained for the spectral analysis. The meteorological variables analyzed in this study, temperature, humidity, wind and pressure, proceed from a 50 m meteorological tower, different 3 masts and microbarographs.

DECADAL CLIMATE VARIABILITY IN CONCEPTIONAL MODELS OF THE ATMOSPHERE AND THE ATMOSPHERE-OCEAN SYSTEM

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To improve the understanding of climate changes beside the influence of external factors on climate, a better understanding of natural climate variability on the decadal and centennial time scales due to internal nonlinear mechanisms is needed. Long-term integrations of simplified conceptional atmospheric models and of the atmosphere-ocean system for 1.000 up to 10.000 years have been carried out to quantify the natural climate variability on time scales of decades to centuries due to internally generated nonlinear dynamical processes and interactions.
The model time series have been used to analyze the dominating atmospheric temporal and spatial pattern using empirical orthogonal functions and time frequency analysis. The dominant mechanisms of decadal climate variability are internally driven by nonlinearities connected with atmospheric processes and generate a frequency spectrum with a large portion of variance concentrated in the decadal time scale.

PASSIVE TRACER FLUXES IN COMPLEX TURBULENT FLOWS

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Geophysical turbulent fluxes are characterized by important non-ideal features. In the well-known case of dispersion of passive tracers in inhomogeneous and non-Gaussian turbulence the flux must be expressed as a functional of the concentration extending the usual flux-gradient relationship. Summarizing the theoretical work we refer to the classical Kolmogorov modification of the heat equation by using a variable dispersion coefficient, and to the work by Lumley (1975) that considers the statistics of particle displacements. Analytical (approximate) results are available for short dispersion times (Hunt, 1985) and for homogeneous non-Gaussian turbulence (Wyngaard and Weil, 1991). A Lagrangian stochastic model (Thomson, 1987) has been used to describe dispersion in many of these situations (e.g. the convective boundary layer or the boundary layer over topography). We examine the detailed predictions of fluxes which can be obtained for prototype cases, and we also compute the statistics of particle displacement. The effective dispersion coefficient may be evaluated both as the ratio between flux and concentration gradient, and as the limit for long times of the ratio of displacement variance and time. The theoretical predictions are then compared with the numerical results, and the magnitude of the higher order corrections is estimated, in order to assess the importance and the practical applicability of refined dispersion theories.

EFFICIENT COHERENT NOISE REJECTION BY GENERALIZED SINGULAR VALUE DECOMPOSITION

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A generic problem in applied physics is the extraction of the dynamics from a system which is polluted by some uncontrollable "noise". Techniques such as the Singular Value Decomposition (or SSA) are of little use for this when the noise is coherent.
However, when a reference data set is available with noise observations only, then the extraction can be considerably improved by generalizing the Singular Value Decomposition. The idea is to project the phase space of the system, or its reconstruction by time-delay embedding, on a non-orthogonal basis that captures most of the dynamics of interest while rejecting the unwanted noise. Two examples from spatio-temporal experiments illustrate the advantages and the limitations of the technique.

A SIMPLE CRITERION FOR DETECTING POTENTIALLY SPURIOUS MULTIFRACTALITY IN LIMITED DATASETS

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Multifractal methods have enjoyed a steady increase in popularity with geophysicists over the past 15 years, i.e., ever since their quasi-synchronous inception in chaotic attractor characterization and turbulent signal analysis. In the former case, we need a singular measure as input; in the latter case, we require a non-differentiable function $f(x)$. In the former case, we consider the scaling behavior of many statistical moments of running sums with respect to the length of the sum; in the latter case, we compute two-point statistics known as "higher-order structure functions:" qth moments of absolute differences between two function values taken at lag r, namely, $D_q(r) = \langle |f(x+r)-f(x)|^q \rangle$. In a scaling regime, we have $D_q(r) \propto r^{\zeta(q)}$ and, as long as there is truly negligible information in the prefactors, $\zeta(q)$ is large-sense concave: $\zeta''(q) \le 0$ (where twice differentiable). [N.B. Being based on sums and differences at all scales, wavelet transforms have since provided a unified framework for the two basic approaches to multifractal data analysis; so our focus on $\zeta(q)$ is actually not that restrictive.] In retrospect, we can view qth-order structure functions as a generalization of the $q = 2$ case —of geostatistics fame in particular— by relaxing the fundamentally Gaussian assumption that 2nd-order moments determine all others. If indeed this is the case, then dimensional arguments lead to $D_q(r) \sim D_2(r)^{q/2}$, hence $\zeta(q) = q\zeta(2)/2$, a linear function as found for *mono*fractal models (e.g., fBm). It is easy to see that this is only an asymptotic result, valid in the limit of an infinite amount of data. We have developed an empirical test for situations were a monofractal model can be considered "good enough;" conversely, we can flag data with *observed* multifractality compatible with its finite scaling range and/or number of realizations.

RESOLUTION OF A NONLINEAR FUNCTION OF A SIGNAL INTO SMOOTH AND SINGULAR OR INTERMITTENT PARTS, USING WAVELET PARAPRODUCT

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This presentation introduces to the geophysical audience, a construction from functional analysis known as the *paraproduct*, by which the singular part of a nonlinear function of a signal may be extracted from the 'smooth' part. That is, the nonlinear function may be written as a sum of two terms, one of which is smooth, the other containing the spatially localized singular or intermittent features. This is accomplished using the orthonormal wavelet transform. Applications to analysis of variance are discussed.

Nonlinear time series analysis in phase space

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A toolkit of algorithms, described in "Analysis of Observed Chaotic Data" [Abarbanel, 1996, Springer-Verlag], for the analysis, characterization, and prediction of chaotic systems has been used on a variety of oceanographic data including surface waves and water levels at tide stations. The toolkit starts with an estimation of the average mutual information and calculation of the global embedding dimension, d_E. This provides sufficient knowledge to form the attractor. The local dynamical dimension (the active degrees of freedom), d_L, is then computed. Finally, the d_L Lyapunov exponents are derived. The largest Lyapunov exponent, λ_1, describes the rate at which nearby trajectories separate, in aggregate, and has been demonstrated to be a good classifier of oceanic phenomena such as water levels. As a practical demonstration of the utility of this approach, a phase space predictor has out performed other methods of temporal ocean water level predictions. A phase space method for prediction one time series from another is demonstrated using data from tide stations at Charleston, SC, USA and Key West, FL, USA.

STATISTICAL PROPERTIES OF DYNAMIC SYSTEMS: DEPNDENCE ON SCALES OF RESOLUTION

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Statistical properties of dynamic systems are examined by the example of a logistic equation. We distinguish four scales of a resulting sequence: (1) internal resolution I, which is the accuracy of calculations, (2) observational resolution E, which is the accuracy of representation, and (3) total length of realization L. Both I and E are regarded as relative values expressed with respect to the maximum amplitude of the process A. Commonly, we imply that I is indefinitely small and E is small enough not to influence the result; however, one cannot expect that actual natural systems should follow these rules. We may readily see, that the total number of the states of the system is $N = A / I$, so if $L > N$ we shall necessarily encounter a repeated value (state) and regard the result as a periodic rather than chaotic, regardless of the value of the control parameter. On the other hand, if $E > I$ (and this is the most common case in treating natural time series) we may recognize the features of a Markov chain in the resulting sequence. The greater is the difference between E and I, the longer is the history one needs to take into account in order to reach the given state. Thus, one and the same process may appear to be chaotic, periodic, or Markovian depending on the scales cited.
These considerations are assessed from the point of view of predictability of natural time series and possibilities of interpolation of chaotic sequences.

NP2

THE SSA-MTM TOOLKIT: APPLICATIONS TO ANALYSIS AND PREDICTION OF TIME SERIES

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A software toolkit for advanced spectral methods has been extensively revised and made available on the Worldwide Web in Spring 1997 (http://www.atmos.ucla.edu/tcd). The toolkit emphasizes, besides the more traditional Blackman-Tukey and maximum-entropy methods, singular-spectrum analysis (SSA) and the multi-taper method (MTM); hence its name. The Toolkit developers and many independent investigators have applied successive versions of the toolkit to a variety of practical problems. The methods themselves are easy to understand and program, but the statistical-significance issue is much more delicate, both theoretically and computationally. A systematic comparison of results from various methods adds considerable insight over the mere statistical testing of any particular method's results. A graphical user interface helps support such comparisons, as well as the "dynamical" testing of results from any given method, by changing interactively the parameters of the method, such as the window width, sampling rate, or resolution of the resulting power spectrum. The talks shows how the SSA-MTM Toolkit tackled these issues and outlines applications to the prediction of interannual and interdecadal climate valiability. It reflects joint work with M.R. Allen, M.D. Dettinger, K. Ide, M.E. Mann, G. Plaut, A.W. Robertson, C. Strong, Y. Unal, R. Vautard, W. Weibel and P. Yiou.

SPATIAL RECONSTRUCTION OF SCALAR FIELDS FOR LARGE RATIOS OF THE NOISE TO RECONSTRUCTING SIGNAL AND UNKNOWN NOISES.

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An approach to reconstruct scalar fields from the noisy data is suggested. It combines spectral representations for field characteristics and special high-effective noise reduction procedure developed by *Ivanov and Margolina* [1996]. This procedure is an optimal filter.
It is demonstrated, that successful reconstruction is possible for the following data.
1. The noise to reconstructing signal ratio is less than 4-5.
2. The ratio of the number of parameters to be determined by the reconstruction (for example, the number of mode amplitudes) to the number of observations should be less than 0.1 to 0.2 and 0.5 to 0.6 for stochastic and deterministic representations of scalar fields, respectively.
3. The spatial resolution of observations should not be less than a few corresponding scales of scalar fields.
4. Noise statistics are unknown.
5. The low-order statistics of the useful signal may also be unknown. However. simple models which give a correlation of the mean characteristics of useful signal should be developed.
The approach are applied to reconstruct the concentration field of SiO_2 in the Kara Sea and climatic chlorophyll field in the Black Sea.

STADY OF NONLINEAR ELASTIC PROPERTIES OF REAL MEDIA BY BISPECTRAL CHARACTERISTICS OF SEISMIC NOISE

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To estimate nonlinear elastic properties of real media, bispectral characteristics of seismic noise are calculated for regions with different geological structure. Within the studied frequency ranges (from fractions to tens of Hz), we obtained a uniform distribution of bispectral amplitudes testifying to the qualitative homogeneity of the medium response to weak seismic actions. On crystalline rocks, bispectral characteristics are close to zero in frequency ranges, which do not contain storm microseisms and industrial harmonics, seismic noise is an almost-Haussian process. On bicoherency maps, triples of phase-coupled industrial harmonics are often clearly seen. On sedimentary rocks, bispectral amplitudes are slightly higher than on crystalline rocks; this may be due to elastic nonlinearity of subsurface soils, however, for definite conclusions, additional data are desirable. Groups of phase-coupled oscillations are found in the frequency range of storm microseisms; however, to determine the cause of their appearance, i.e., features of generation and propagation of microseisms, or nonlinear effects, recordings from stations disposed at various distances from the source of microseisms are necessary.

NONLINEAR SPECTRAL ANALYSIS AND THE POSSIBILITY OF ITS USE IN PREDICTING THE 23 CYCLE OF SOLAR ACTIVITY

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From the present point of viewthe processes on Sun may be considered in the context of nonlinear dynamic system. Consequently, the indices determined the solar activity level characterize the behaviour of such system. The nonlinear spectral analysis of the time-dependent data set of Wolf numbers confirms this to be true. An attempt was made to construct the nonlinear spectral model of the average monthly Wolf numbers over the period from 1749 to 1997 and to extrapolate it to the future with the purpose of predicting the parameters of the 23 cycle of solar activity. This model permits to predict the value and the time of the peak height of the forthcoming cycle.
This method of nonlinear prediction may be used in the modelling and predicting many other real physical processes on Sun and Earth.

RESEARCH OF QUASIPERIODIC PROCESSES BY A RESONANCE METHOD

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As the basic problems of the analysis of quasiperiodic processes is possible to consider: search of periodicity, restoration of the missed observations from the available information (construction of model in view of physics of the phenomenon), extrapolation (forecast) for limits of an interval of supervision. They offer the new method of the resonance analysis. The method is free from lacks inherent to classical methods. To lacks relating it is possible: a multiplicity of frequencies, false spectral lines, the problem of calculation of a true initial phase, amplitude, the problem of separation of neighboring periods and so on. This method allows to investigate irregular one and two-dimensional time series with a high level of noise. The method allows to find the basic parameters of researched processes with anyone by the beforehand given accuracy. There are many applications of the method in the areas in geophysics, geodynamics. The method allows to make the forecast at the limited quantity and quality of the initial information about researched process. The method has shown the high efficiency at research of a trajectory of movement of an instant pole of rotation of the Earth (Chandler's motion), and at research of dynamics of atmospheric processes.

ANALYSIS OF SELF-AFFINE LOG-NORMAL TIME SERIES

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Self-affine time series are characterized by a statistical distribution of values and by their persistence. While most previous studies have been restricted to Gaussian (normal) distributions, many geophysical time series are better approximated by log-normal distributions, an example is river discharge. One measure of persistence is β, where the power-spectral density (S_m) depends upon frequency (f_m) according to $S_m \sim f_m^{-\beta}$. We use a variety of techniques to quantify the strength of persistence of synthetic self-affine time series with $-3 \le \beta \le 5$, and log-normal distributions with coefficient of variation, c_v = 0.2, 0.5, 1.0. Semivariograms and rescaled-range analyses quantify the strength of persistence over, respectively, $1 \le \beta \le 3$ and $-1 \le \beta \le 1$. Rescaled-range estimates of the persistence worsen for log-normal noises with increasing c_v. Both Fourier spectral techniques and wavelet variance analyses quantify the strength of persistence for all β; however, wavelet transforms have a fractal basis and several advantages over Fourier transforms. Wavelet analyses locate periodic and non-periodic events permitting transient or time-dependent features to be detected and lack many of the inherent problems that are found in Fourier power-spectral analyses. The output of the wavelet transform, $W(t, a)$, depends on the wavelet width, a. The variance of the wavelet amplitude, V_w, has an excellent power-law dependence on a, such that $V_w \sim a^{Hw}$. The wavelet variance exponent, Hw, is equal to β, the power-spectral exponent. A variety of applications to "actual" self-affine time series are shown.

DERIVING STOCHASTICAL DYNAMICAL MODELS FROM NOISY TIME SERIES

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A methodology of constructing nonlinear stochastical dynamical models from a high-dimensional time series contaminated with observational noise is presented. The multivariate dynamical field is projected onto a linear subspace spanned by relatively few characteristic spatial modes called principal interaction patterns. The expansion coefficients of these patterns are assumed to be governed by a nonlinear dynamical system specified with free parameters within a suitably chosen model class driven by Gaussian white noise. The optimal dynamical model is determined by identifying the spatial patterns and the system parameters (i. e. the parameters of the deterministic drift term and the covariance matrix of the noise term) simultaneously from a time series using a Maximum-Likelihood-Principle. The performance of the method is demonstrated using numerically generated data.

ON EMBEDDING REALISTIC DATA

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Many common statistics estimated from nonlinear time series analysis assume that the data has been embedded in a way so as to reconstruct the underlying dynamical system, for example via a time delay procedure. It is well known that successful reconstructions allow the estimation of many useful dynamical variables, yet the relevant theorems do not apply even for accurate observations of finite accuracy. We illustrate both how the embedding approach works and why it often fails, using 8 bit data from low dimensional systems. This suggests the introduction of consistency tests which are trivially passed when the theorems of deterministic dynamical systems apply, and often fail for observations of physical systems. The goal is to identify when and where they fail. This prevents us from subsequently drawing false conclusions about the system we are analysing. Applications toward identifying short term predictability and state dependent model error are presented.

DYNAMICS OF TEMPORAL DISTRIBUTION OF CAUCASIAN EARTHQUAKES

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It is well known that lithospheric processes related to earthquake generation are highly complicated. Quantitative and especially quantitative evaluation of dynamical properties of mentioned processes demand implementation of modern tools of nonlinear time series analysis. For last decade many investigation were devoted to search for chaotic properties of seismicity. Majority of published results led to the conclusion that low-dimensionality of temporal distribution of earthquakes, contrary to their space distribution, is unlikely. In present study we investigated dynamical properties of seismicity in Caucasian region using methods of nonlinear analysis, by consideration magnitude sequences and interevent interval time series. We have carried out both qualitative (autocorrelation functions, power spectrum, 2 and 3 dimensional phase portraits, Poincare sections etc.) and quantitative (correlation dimension estimation by Takens best estimator) analysis of whole mentioned time series both before and after large events. We evaluated also persistence in our time series using Hurst method of R/S analysis. As it was shown considered time series, in accordance with literature data reveal absence of low dimensionality of temporal evolution of magnitude and interevent time intervals for earthquakes of Caucasian region. Indeed correlation dimensions for all investigated series are at least higher then - 8. At the same time mentioned processes are not quite random. Moreover, by analysis of time series before and after largest regional events for sufficiently long time period it was shown that nonlinear structure of temporal distribution of seismic processes before and after large earthquake are different, although they still remain highdimensional. Generally, existence of nonlinear structure in dynamical properties of earthquake temporal evolution was indirectly confirmed by differences in persistence of considered time series before and after large event and by reliable difference of Hurst exponents for real and randomized time series.

TESTING FOR AN ATTRACTOR IN THE SOLAR WIND

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A time series of velocity fluctuations of the low-speed stream of the solar wind is analysed as measured by the Helios spacecraft in the inner heliosphere, which is a region of space dominated by the solar wind flow. A method of singular system analysis is invoked to give a faithful representation of a fractal structure in the solar wind. In this way, the data are represented in terms of a complete set of orthogonal functions, obtained from a numerical analysis of the data. This results in better characteristics of the fractal structure. We have supported our previous result that trajectories describing the system in the inertial manifold of phase space can asymptotically approach the attractor of low-dimension. Furthermore, the obtained characteristics of the attractor are significantly different from that of the surrogate data. Thus the results of these tests suggest that the inner heliosphere is *nonlinear* deterministic system, at least in the inertial manifold of the phase space of this complex high-dimensional system.

SPECTRAL-TEMPORAL STRUCTURE OF NONLINEAR-PARAMETRIC EFFECTS IN ROCKS AS AN INDICATOR OF A GEODYNAMIC MODE.

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Nonlinear-parametric characteristics of rocks are one of the most efficient indicators of their stressed-strained state due to high tensosensitivity. These characteristics have been used for long for monitoring of natural and technogenic geodynamic processes of different scale, in particular, at seismoprognostic investigation in the Ukrainian Transcarpathians. The effects are investigated using original techniques and equipment, and are both good indicators of stimulated seismotectonic processes and local earthquake precursors. Thus, several time increase of spectral amplitudes within the range of 1-30 hours has been detected due to spestral-temporal analysis of parametric seismogeoacoustic data. This increase begins 3-5 weeks before local earthquakes, and creep "miniearthquakes" are observed on this background. Creep tensovariational storms with variation amplitudes increasing by tens and hundreds of times begin several days before the event.

THE FRACTAL ANALYSIS OF NOISES WITH SPECTRAL FUNCTION $G(\omega)=1/\omega^{\lambda}$

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The fractal dimension D of random time serieses with spectral function $G(\omega)=1/\omega^{\lambda}(0.2<\lambda<6)$ was considered. The principal problem was to search empirical dependence D via parameter λ. The method of R/S functions was used for solution of the problem.

It was shown that the dependence D from λcould be devided in two domains.

In the first range $(0.2<\lambda<1)$ D depends on λ and the second one $(0.2<\lambda<1)$ corresponds to the case when D is independent from λ.

Besides the dimension D depends on the length of interval of time series N. For small values of N the value of the dimension D is smaller than the one for larger values of N.

In report the conclusion was made that it is possible to use fractal dimension for analysis of flikker noises.

ENHANCED MONTE CARLO SSA FOR DETECTION OF MODES WITH NONTRIVIAL DYNAMICS EMBEDDED IN COLORED NOISE

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Singular spectrum analysis (SSA) is a useful tool for identification and extraction of oscillatory or other signals from noisy background. Its basic form, however, is reliable when a signal is embedded in white noise, while presence of "colored" noises could lead to spurious results. Recently, Monte Carlo SSA, based on so-called surrogate data technique, has been introduced in order to increase reliability of detecting signals embedded in colored noises, which are usually present in geophysical data. We propose to enhance the Monte Carlo SSA by evaluating and testing regularity of dynamics (quantified by so-called coarse-grained entropy rates) of the SSA modes against the colored noise null hypothesis in addition to the test based on variance (eigenvalues). We demonstrate that such an approach can enhance the test reliability in detection of relatively more regular dynamical modes than those obtained by decomposition of colored noises. in particular, in detection of irregular oscillations embedded in red noise. The method is demonstrated in detection of near-decadal oscillations in historical temperature records obtained from several European locations, as well as in detection of 3–5 year oscillations in the global temperature series, related probably to the ENSO cycle.

CHAOS AND THE (BROKEN) BOOTSTRAP

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Inasmuch as Lyapunov exponents provide a necessary condition for chaos in a dynamical system, confidence bounds on estimated Lyapunov exponents are of great interest. We examine the bootstrap approach as a framework for quantifying sampling uncertainties, and demonstrate that it is inappropriate for multiplicative-ergodic statistics of deterministic chaos; this remains unchanged in the presence of observational noise. For aleatoric dynamics (nonlinear stochastic processes), we introduce a dynamically conditioned bootstrap approach for multiplicative-ergodic statistics such as Lyapunov exponents. A alternative approach towards quantifying the minimum duration of observations required to estimate global Lyapunov exponents is suggested; this approach provides a necessary (but not sufficient) condition by determining whether a particular finite time exponent might provide a good approximation to the global Lyapunov exponent and is applicable to both deterministic and stochastic systems. Arguments are advanced, which suggest that it is not possible to state sufficient conditions in the case of deterministic dynamics.

RISK ANALYSIS OF GLOBAL CHANGE

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Earth System changes are taking place on a variety of temporal and spatial scales. Especially rather short and medium term processes like the enhanced greenhouse effect or the massive erosion of fertile soils all over the world are equally threatening and related to human activities. In this presentation a novel approach to analyse these global environmental changes is presented which aims at the formu- lation of 'risk avoiding' strategies. Based on simple models and frameworks a risk analysis is carried out which takes into account both. the knowledge and the policy induced uncertainty of the relevant systems. The approach is illustrated along the climate system where a risk analysis with respect to a 'untolerable climate evolution' is carried out.

THE IRRELEVANCE OF CHAOS IN FORECASTING AND "TINY" DATA SETS

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Inasmuch as Lyapunov exponents provide a necessary condition for chaos in a dynamical system, confidence bounds on estimated Lyapunov exponents are of great interest. We examine the bootstrap approach as a framework for quantifying sampling uncertainties, and demonstrate that it is inappropriate for multiplicative-ergodic statistics of deterministic chaos; this remains unchanged in the presence of observational noise. For aleatoric dynamics (nonlinear stochastic processes), we introduce a dynamically conditioned bootstrap approach for multiplicative-ergodic statistics such as Lyapunov exponents. A alternative approach towards quantifying the minimum duration of observations required to estimate global Lyapunov exponents is suggested; this approach provides a necessary (but not sufficient) condition by determining whether a particular finite time exponent might provide a good approximation to the global Lyapunov exponent and is applicable to both deterministic and stochastic systems. Arguments are advanced, which suggest that it is not possible to state sufficient conditions in the case of deterministic dynamics.

EL NIÑO CHAOS: PRONOUNCED NOISE INDUCED EFFECTS AND STOCHASTIC RESONANCE IN A MODEL OF THE ENSO CYCLE

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An alternative approach for explaining aperiodicity and chaos in the El-Niño-Southern-Oscillation (ENSO) is proposed, which considers the ocean's equatorial wave dynamics as part of a nonlinear dynamical system driven by random environmental fluctuations. Noise excitation causes the model to jump chaotically between different interacting oscillations generated by the system's implied "Pacific ocean-atmosphere" cycle and the seasonal cycle. The injection of noise induces chaotic dynamics, triggering an El Niño whenever the model's thermocline depth exceeds a threshold level. A "stochastic resonance" arises – should noise intensity deviate substantially from optimal, the regular development and coherence of the ENSO cycle is impeded. The model's noise induced chaos provides an attractive explanation for the sporadic yet deterministic character of El Niño events.

Using Nonlinear Approaches to Predict Predictability and Transitions in the Atmospheric General Circulation

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We present evidence that a hemispheric measure closely related to available potential energy is characterized by a low-dimensional dynamical system. The evidence is supported by three nonlinear time series analysis approaches, namely, dimension estimates, nonlinear prediction and Lyapunov exponents calculation. We then were able to demonstrate that 1) this dynamical system can explain large scale circulation changes, and 2) nonlinear prediction may be able to provide very good prediction of local Lyapunov exponents (local predictability).

LINEAR AND NON-LINEAR TIME SERIES ANALYSIS OF CYG X-1

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We analyze a RXTE observation of the black hole candidate Cyg X-1 by the linear state space model and search for effects of nonlinearity by surrogate data testing. The state space model reveals a relaxator on short time scales. Surrogate data testing shows that it is not a linear relaxating process. Furthermore, it suggests nonlinear effects on long time scales. We investigate the significance of this result by simulation studies based on the fitted linear state space model.

ANALYSIS OF SEISMIC DYNAMICAL SYSTEMS

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A procedure is presented for the analysis of complex stationary time series for which the Fourier power spectra reveals broadband noise or broadened pulses. We first determine the Hurst exponent from which we may know whether the time series under study is mainly random or if the data points present correlations. If the data are correlated, a chaotic analysis will reveal whether they may be interpreted as a low dimensional nonlinear system (defined by a low correlation dimension and a finite and positive Kolmogorov entropy and largest positive Lyapunov exponent) or as a stochastic process. We have studied three kind og temporal series: interevent time series of infrasonics recorded at Stromboli volcano, and, S-coda waves and microseisms, that have been recorded at the eastern Pyrenees. Results show that microseism and Coda waves can be modelated as a low dimensional deterministic system, Correlation dimensions 2.3, 3.2, respectively. At the contrary infrasonic has resulted stochastic. This chaotic character can be attributed to the medium properties. Coda waves with scattering through a fractal distribution of scatters or to multiple reflexion inside resonators (for example sedimentari basins) and microseisms as a propagation of wave guide of variable cross section, this character is well reproduced by a nonlinear forced oscillator.

VARVED PLEISTOCENE LAKE SEDIMENTS IN NW ARGENTINA AS ARCHIVES OF PALEO-CLIMATE DYNAMICS: COMPARISON OF PAST AND MODERN RAINFALL VARIATIONS

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Climatic shifts towards more humid conditions and enhanced intra- and interannual rainfall variations is one of several influential factors causing landslides in high mountains (see also session NH3-5). In order to test this hypothesis for the NW-Argentine Andes, both modern and past precipitation variations have been analyzed. Modern rainfall data show a strong influence of two major climate oscillators, the Atlantic sea-surface temperature (SST) dipole and the El Ni±o/Southern Oscillation (ENSO). Whereas the Atlantic SST dipole consistantly increases tropical and subtropical South American rainfall with mean periodicites of 10 to 13 years, the ENSO causes a complex spatial pattern of rainfall anomalies either with a significant increase or decrease in total rainfall during El Ni±o years: in NW Argentina modern precipitation appears to be slightly reduced during these events. The past precipitation changes have been reconstructed from annual-layered (varved) deposits of a >35 kyr landslide-dammed lake in the Qda. de Cafayate (25 59'S 65 46'W). Color changes in the varves are used as a proxy for river influx into the lake, inferred to be linked to precipitation changes. In addition, the dynamics of the lake ecosystem has been reconstructed from silica- algae assemblages and the sediment composition. The comparison of rainfall variations through time shows that both today and during landsliding the Atlantic SST dipole slightly increased local rainfall; however, in contrast to present conditions the ENSO increased precipitation at the time of the landsliding event with mean periodicites of 3 to 5. Future changes in the spatial distribution and extension of ENSO-related precipitation anomalies could therefore increase the risk of future landslides in this region.

COMPLEXITY ANALYSIS OF LONG-TERM TIME SERIES FROM THE HUBBARD BROOK ECOSYSTEM STUDY

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We demonstrate that the application of nonlinear methods to hydrological and biogeochemical time series can give valuable insights into the structure and function of ecological systems. Focus is on long-term data from the Hubbard Brook Ecosystem Study. We investigate complexity, information-theoretic and spectral measures, such as entropy, fluctuation complexity, mutual information, or power spectrum. The information gathered is complementary to conventional statistics as well as process-oriented modeling. One possibility to approach understanding of ecosystem behavior is to ask for the *transformation* performed by the system on input when producing corresponding output signals. This transformation is indirectly characterized through differences in the general temporal structure of precipitation, solutes, and runoff. Several catchments from this site are compared and their ability to reduce information content is demonstrated.

NP3 Transport and mixing in geophysical flows

Convener: Legras, B.

01 Transport and mixing in stably stratified fluid

Convener: Staquet, C.

NON-EQUILIBRIUM OSBORN-COX MODEL FOR OCEAN AND ATMOSPHERE MICROSTRUCTURE FLUX ESTIMATES

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Experimental and computer simulation studies of homogeneous stably stratified turbulence provide a framework for generalizing the Osborn-Cox model used by oceanographers (and potentially by meteorologists) to infer heat and momentum fluxes from turbulence microstructure data. In the asymptotic region of exponential growth, turbulent kinetic and potential energies have the same growth rates, which may be parameterized in terms of the Richardson number Ri, microscale Reynolds number R_λ, and shear parameter SK/ϵ. These three parameters can be simultaneously measured by contemporary ocean microstructure profilers, while resolution of the dissipation rate ϵ is apparently not yet possible with atmospheric profilers. Scaling of the TKE and PE equations yields approximate analytical expressions for the growth rates which provide useful fits to the data. The resulting expressions can, in principle, be used to infer turbulence growth rates and heat and momentum fluxes leading to small scale turbulent mixing. Prospects for application to oceanic and atmospheric data sets, as well as to our current laboratory experiments utilizing approximately instantaneous vertical sampling will be discussed.

INTERNAL GRAVITY WAVE BREAKING IN THE MIDDLE ATMOSPHERE: TWO- AND THREE-DIMENSIONAL NUMERICAL SIMULATIONS

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Transfer of momentum from the wave field to the mean flow associated with internal wave breaking is an important effect determining local mixing as well as vertical distribution of winds in the atmosphere. Appropriate representation of the momentum flux is also a key issue in the design of "subgrid" parameterizations for general circulation models. New results from a sequence of 2D and 3D numerical simulations of the evolution of monochromatic internal gravity waves induced by a topographic forcing in a periodic domain will be presented. Strong dependence of the dynamics of wave mean-flow interaction on the degree of hydrostaticity of the wave is observed. In particular, a highly non-hydrostatic wave (which propagates almost vertically) breaks at a relatively low altitude forming a narrow jet-like flow of negative velocity which, in turn, arrests further upward propagation of the wave. In the opposite limit of a hydrostatic wave, breaking starts at high altitude and extends through the entire depth of the fluid layer. Clear evidence of the development of spanwise perturbations in the breaking wave is observed in high-resolution 3D simulation.

PARTICLE DISPERSION AND MIXING BY BREAKING INTERNAL GRAVITY WAVES

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We provide estimates of diapycnal mixing induced by breaking internal gravity waves using two methods. The first method consists in a direct evaluation through particle dispersion while the second relies upon potential energy budgets. We investigate both standing and propagating breaking waves, whereof dynamics were previously analyzed by means of direct numerical simulations. A local estimate of mixing is first inferred from the time evolution of sets of particles released in the flow during the turbulent regime. We show that after an early evolution dominated by shear effects, a diffusion law is reached. The diffusion coefficient, K, is also calculated from the diffusive flux across the isopycnals. An excellent agreement with the former method is obtained. This finding is of particular interest regarding the interpretation of in situ estimates of K, either inferred from tracer dispersion or microstructure measurements. We show that the result of mixing is a vertical layering of the density profile made of a superposition of less stratified layers and more stratified layers. We then give insight on the mechanisms of formation of this vertical layering.

LONG INTERNAL WAVES OF FINITE AMPLITUDE IN THE FLUID WITH A DENSITY JUMP

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The propagation of the long internal waves of finite amplitude in the two-layer fluid is considered. The analytical expressions for the components of the fluid particle velocity, elevation of the basin's surface and layer's interface up to values of the second degree are obtained basing on expansions of the velocity potentials in the upper and lower layers and using the Lagrange's technique taking account of dispersion with subsequent writing of desired solution as an expansion in powers of the amplitude parameter. The relations allowing to estimate the dispersion effect and the applicability of the approximation of "solid cover on the basin's surface" are derived.

Basing on the two-layer density model, the analogous investigation is carried out for the long internal waves running onto the vertical wall. The non-linear disturbance amplitudes are compared with the incident wave amplitude in the case of the open water, as well as in the case of "solid cover" approximation.

DYNAMICS OF INTERFACES AND LAYERS IN A STRATIFIED TURBULENT FLUID

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A model of mixing in a stratified and turbulent fluid which uses the horizontally averaged vertical buoyancy gradient and the density of turbulent kinetic energy as variables is proposed. Heuristic 'mixing-length' arguments lead to a coupled set of parabolic differential equations. A particular form of mechanical forcing is proposed; for certain parameter values the relationship between the buoyancy flux and the buoyancy gradient is non-monotonic and this leads to an instability of equilibria with linear stratification. The instability results in the formation of steps and interfaces in the buoyancy profile.
The turbulent mixing process can take one of three forms depending on the strength of the initial stratification. When the stratification is weak, instability is not present and mixing smoothly homogenizes the buoyancy. At intermediate strengths of stratification, layers and interfaces form rapidly over a substantial interior region bounded by edge layers associated with the fluxless condition of the boundaries. The model predicts a third case, when the central region is linearly stable and no steps form there.

GENERAL PROPERTIES OF THE FREE STRATIFIED FLOWS (LIE GROUPS ANALISYS AND SMALL TIME ASIMPTOTICS)

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The symmetry properties of the complete set of governing equations in 1D, 2D and 3D cases for free stratified flows are analysed by continuous groups methods. The symmetry group of the 1D stationary equations is not the subgroup of non-stationary one. All 2D and 3D transient problems have the same symmetry groups structure. There were found non-trivial invariant solutions of non-linear stratified flows equations which do not follow directly from quality analysis and from physical sense of the problem. The asymptotic solutions of linearized transient 1D, 2D and 3D boundary problems are found. Flow structure is analysed in detailes for diffusion induced currents on impermeable perfect shape surfaces (inclined plane and channel, horizontal cylinder, sphere) submerged in a rest continuously stratified liquid. Solutions are analytical functions of the all physical parameters of the problem (gravity acceleration, buoyancy frequency, viscosity and diffusion coefficients). These solutions are matched both with the known exact solutions and themselves in limit cases. The asymptotic solution of the starting cylinder problem is constructed. Solutions are compared with the known results and with data of laboratory experiments. Extrapolation of the developed models on the description of the environment (the atmosphere and oceans flows) is discussed.

ON TWO DIMENSIONAL APPROXIMATION OF THE WIND-WAVE INTERACTION PARAMETER

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An air flow of arbitrary direction over a two dimensional monochromatic wave surface is considered. The angle–frequency dependence of the wind-wave interaction parameter β is studied. The research is carried out using the three dimensional model of the wave boundary layer. The interaction parameter β is considered as a function of two arguments: wave component frequency ω and angle θ between wave and wind directions. The values of β for $\omega \in (0.033, 0.4)g/v_*$ (g — gravity, v_* — friction velocity) and $\theta \in (0, \pi)$ are computed in numerical experiments with the wave boundary layer model. The change of wind direction with respect to the wave phase speed direction is qualitatively equivalent to the decrease of wave frequency and the increase of its phase speed. When the equivalent phase speed coincides with the wind velocity the wind–wave interaction is equal to zero. Further increase of the angle θ leads to the case when the equivalent wave moves faster than wind and the wind–wave interaction parameter changes its sign. The Fourier analysis of the angular dependence of β shows that only the first three Fourier components are significant. This allows derivation of simple approximate formula which values are in good agreement with computed data.

INVESTIGATION OF THE VERTICAL STRUCTURE OF THE FAR-WAKE OF A SPHERE IN A STRATIFIED FLUID

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We focus on the large-scale structures in the far-wake of a sphere ($Nt > 20$), after the near-wake has collapsed under the effects of stratification and the vortices have lost their vertical velocity component, leading to quasi two-dimensional turbulence. Two techniques were used to study the vertical evolution of the horizontal motions at $F = 0.4$ (laminar near-wake) and $F = 6$ (turbulent near-wake): particle tracking and fluorescent-dye visualization. In both techniques, a laser-sheet was used to vertically scan a succession of horizontal planes. The evolution of vorticity in the vertical direction demonstrates that the vertical diffusion of the vorticity is similar to purely viscous diffusion. Moreover, analysis of the vertical evolution reveals a high degree of vertical coherence of the vortices in the laminar case. However, due to advection, the vortices are slightly inclined with respect to the vertical direction. To examine the internal structure of the far-wake vortices we also measured the density variations within the vortices. Horizontal as well as vertical density profiles were obtained from high sensitivity micro-conductivity probe measurements. The results reveal a three-dimensional internal structure of the vortices. Specifically, this three-dimensional structure is in accord with a model to explain the equilibrium of the "quasi two-dimensional" vortex structures.

CONVECTIVE MOTION DRIVEN BY LOCALIZED SUDDEN COOLING OF HEATING EVENTS ON THE SURFACE OF THE SEA.

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A bidimensional, non rotating, stochastic model for deep water formation is shown. A series of random, localized, sudden cooling or heating events on the surface of a stationary sea is stated. Every push is considered as an infinite series of speeching linear quadrupoles of wires, localized sources of vorticity. A short times analytical solution is presented for an homogeneous, stratified, unviscous, viscous, diffusive, non diffusive model; the seperate effect of each of these components (stratification, viscosity, diffusivity) is discussed, if N^2, ν, k are given functions of the depth. This is a first step in order to study the effect of a non homogeneous, stochastic buoyancy flux on a non rotating sea.

TRANSPORT AND MIXING IN 3D LAMINAR FLOWS

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Understanding particle advection in incompressible laminar fluid flow, apart from being of theoretical interest, holds much relevance for technological applications. Properties of emulsions, dispersion of contaminants in the atmosphere and ocean, sedimentation, and mixing, are just a few examples. Chaotic advection is the complex behaviour a passive scalar — a fluid particle, or a passively advected quantity such as temperature or concentration of a second tracer fluid — can attain, driven by the Lagrangian dynamics of the flow. The surprise is that even laminar flow at low Reynolds number is capable of producing such complex behaviour. The importance of chaotic advection lies not least in the enhancement of transport it produces. In this respect, one can single out the phenomenon of resonance-induced dispersion in three-dimensional laminar flow for special attention. Here we report on recent theoretical progress in the understanding of resonance-induced dispersion and its importance for mixing and transport. We speculate on possible applications to geophysical flows.

ON THE STATIONARY SPECTRA OF WEAKLY NONLINEAR INTERNAL GRAVITY WAVES IN 2 AND 3 DIMENSIONS

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The weak turbulence approach consists in using perturbation theory in wave amplitude and Gaussian statistics for an ensemble of weakly nonlinear waves in order to get a kinetic equation for the wave amplitude density. We apply this technique to the internal gravity waves in the Boussinesq approximation and generalize the earlier results [1] obtained for the case of unidirectionally propagating plane waves. Both 2d case of planar waves and 3d case (the Craya - Herring basis is used in this latter case) are studied. The essentially anisotropic (in vertical and horizontal components of the wavenumber) Kolmogorov - type energy spectra are found from the stationary solutions of the kinetic equations. These spectra may provide an alternative explanation of the "-3" spectra in vertical wavenumber, widely observed in the atmosphere

References

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THE LIFE CYCLE OF A STRATIFIED SHEAR LAYER

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We investigate the detailed nature of the "mixing transition" through which intense turbulence may develop in stratified free shear layers. We explicitly quantify the time–evolving irreversible mixing which occurs within the flow, which requires us to consider in detail the evolution of streamwise vortical streaks, which develop once the primary Kelvin–Helmholtz billow saturates. Using the numerical data from a sequence of three–dimensional simulations with varying stratification, we accurately track the nonlinear amplification of these intermediate coherent structures, verifying that they are well–predicted by secondary stability analysis, and are due to a convective destabilization of the periphery of a Kelvin–Helmholtz billow. At all times we calculate the minimal potential energy of the system accessible by (notional) adiabatic rearrangement of fluid parcels, and so quantify continuously the irreversible "mixing". The nonlinear amplification of the streamwise vortices is driven principally by the mean shear. Vortex stretching leads eventually to a violent subcritical vortex–vortex collision which drives the dominant mixing process in the flow life cycle. An appropriate definition of the "mixing efficiency" implies that the irreversible small–scale mixing of the density which is triggered by shear layer transition leads inevitably to a density "staircase", with regions of well–mixed fluid separated by narrow regions of relatively strong density gradient.

GRAVITO-INERTIAL WAVES IN A ROTATING STRATIFIED SPHERICAL SHELL

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We present computations of axisymmetric eigenmodes of a stably stratified rotating spherical shell. The spectrum is divided into four classes corresponding to ellipsoidal and hyperboloidal turning surfaces. A spectral band of regular modes leading to smooth structures has been found but the majority of modes is singular with structures featured by a web of characteristics. These characteritics generated by an Ekman layer singularity reflect both on the turning surfaces and the boundaries. Many of these patterns are space filling but some limit cycles on which characteristics are attracted can be found. These attractors are the best candidates to transport chemical elements or angular momentum in the non linear regime. The discovery of geometrical focusing corresponding to a focusing of energy towards particular corners suggests that many modes should disappear without efficient dissipative process. Asymptotic behaviours at weak viscosity are then discussed.

NP3

INTERNAL WAVES, TURBULENCE AND DISCONTINUITIES IN A STRATIFIED WAKE

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Schlieren devices, dyeing, density markers, probes and echosounder are used for studying of a 3D and 2D stratified wake in laminar, vortex and turbulent regimes. Effect of self consistent high gradient interfaces on wake geometry is studied in details. Due to the intensification of the initially weak stratification (up to 150 times past a cylinder) these high gradient interfaces determine the flow geometry, instability, and transport of contaminants. These interfaces form envelope of a density wake, shell of vortices and on soaring discontinuities inside internal waves. Soaring interfaces are treated as internal boundary currents in a fluid interior. They are formed due to separation of the boundary current and interaction of large scale elements of motion. Several types of small and large scale instabilities are identified. Extended classification of flow regimes is presented. Besides the active turbulence the "structural turbulence" when complicated relief of isopicnes is formed on the background of smooth velocity profiles is observed. Optical and acoustical images of the active turbulence in a wake are different and mutually compliment each other. Description of the observed flow is based on scaling analysis complete set of equations and boundary conditions. Appropriate ratios of five basic and combined scales describe boundaries on the flow regimes diagramm.

MOLECULAR DIFFUSION OF PASSIVE ADMIXTURE IN STRATIFIED FLOWS

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Geophysicists have long been aware that laminar motions are markedly affected on the molecular transfer of temperature and concentration of passive species. Here we consider the influence of simple streamline flow on the admixture diffusion. The concentration of passive admixture $n(\mathbf{R},t)$ is governed by the well known equation

$$\frac{\partial n}{\partial t} + div n\mathbf{v} - D\Delta n = q(\mathbf{R},t), \qquad (1)$$

where D is the molecular diffusivity, $\mathbf{v}(\mathbf{R},t)$ is a velocity vector which may be prescribed arbitrarily, $q(\mathbf{R},t)$ is the prescribed distribution-function of admixture sources. Let us assume that $\mathbf{v}$ is a simple vortex flow

$$\mathbf{v} = (\alpha + \beta z)\mathbf{x}_0. \qquad (2)$$

Here α and β are costantes, $\mathbf{x}_0$ is the unit vector of x axis. The general solution Eq. (1) may be expressed by means of some generalized Airy integral. Some particular solutions of Eq. (1) with $\mathbf{v}$ from (2) are considered in detail, e.g. a Green function of Eq. (1). The influence of simple vortex flow (2) on the molecular diffusion have been clarified to a large degree.

OBSERVATIONS OF TURBULENCE AND MIXING IN CLOUDS AT THE CENTIMETER SCALE

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Airborne measurements of turbulence in the atmosphere are presently limited to scales larger than a few meters for the dynamics. In clouds, droplets can be considered as tracers of the fine scale motions and new airborne spectrometers provide a unique way of analysing turbulence at scale as small as a centimeter. Such processes are of crucial importance for the evolution of the droplet spectra and the onset of precipitation. Various numerical studies of this process have been conducted with direct numerical simulations (DNS) showing that the droplet inertia in small scale vortices should generate concentration inhomogeneities much more significant than a basic droplet random distribution should do. The consequences are strong dispersion in the droplet spectra and an increased precipitation efficiency in clouds. Statistical analysis of the series of droplets counted with a new spectrometer will be presented. They show on the contrary that the droplets seem to be randomly distributed without any preferential concentrations. These results are important for the description of the coupling between turbulence and inertial particles at large Reynolds numbers and low Stokes numbers, conditions that are difficult to simulate numerically.

THREE-DIMENSIONAL STRUCTURE OF BREAKING MOUNTAIN WAVES

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Flow of a uniformly stratified fluid over a mountain leads to stationary lee-waves. For sufficiently high mountains the lee-wave situated above the mountain becomes gravitationally unstable and breaks, resulting in a localized turbulent zone. The ensuing flow is characterized by a considerable increase in drag and a strong acceleration of the fluid between the breaking zone and the mountain. To examine the instability leading to this condition and the resulting new flow configuration, two- and three-dimensional mountains were towed in linearly stratified saline solutions. After an initial steepening period, the streamlines associated with the lee-wave are eventually forced to overturn into an S-shape. Clearly, a condition of static instability is reached in this region of the flow. Surprisingly, the instability following this condition is strongly three-dimensional, even in the case of a two-dimensional mountain. As the maximum upstream deflection of the streamlines becomes horizontal, the streamlines deflect simultaneously in the spanwise direction. A short time after, the fluid rolls-up into toroidal vortex structures with significant vorticity components in all three coordinate directions, in contrast to a Kelvin-Helmholtz roll-up. Unlike the usual coherent structures found in a stratified environment, the characteristic vertical scale of these vortices is of the same order as the horizontal scale.

DISPERSION IN THE STABLY STRATIFIED ATMOSPHERIC BOUNDRY LAYER

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Dispersion of trace substances in the turbulent boundary layer of the atmosphere is of major practical interest for environmental problems. Whereas dispersion in homogenous background turbulence is well understood, stable stratification adds much complexity to the problem. This is not only due to unisotropy of stratified turbulence but also due to effects of intermittency, internal waves, inversion layers or inertial oscillations which can be observed in the atmospheric boundary layer. We will discuss the influence of these effects on the dispersion of trace substances by means of numerical simulations and observations.

THE BEHAVIOR OF DIFFERENT NUMERICAL SCHEMES FOR PASSIVE TRACER ADVECTION

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Different numerical schemes for advection can produce significantly different results within ocean models. Numerical errors are particularly large where either currents are under resolved or features in the advected field are under resolved. In the low resolution configurations of ocean models which must necessarily be used today for climate study, poor resolution is inescapable. Even in the highest resolution basin scale models one finds that certain features are seriously under resolved. We present results of tests of advection schemes within the simple gyre circulation described by Stommel (1948). Within this time-independent gyre the behaviour of the various advection schemes is clearly evident, unobscured by other processes. Schemes considered include most of those used in primitive equation ocean models today. New aspects of this presentation include an improved configuration of the Stommel Gyre which challenges the multidimensional performance of the schemes, and the use of a closed form solution which has been derived in order to produce the exact final state solution against which the performance of the numerical schemes is measured.

FLUID TRANSPORT BY COHERENT VORTICES

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Propagating vortices have a significant impact on mixing processes in the ocean, in coastal regions, the surf zone as well as large-scale processes in the atmosphere. We focus on the drift component of fluid transport by an isolated vortex, and demonstrate that this is the dominant contribution to fluid transport. The transport properties of coherent vortices propagating on an f-plane are studied experimentally by examining the distortion of a series of dye-lines. The observations are compared with a model based on characterizing the flow around the vortex as irrotational flow past a rigid cylinder of volume $\mathcal{V}$. For a dipolar vortex, the measurements made of the volume of fluid permanently displaced forward agree to within 20% of that predicted by Darwin's (1953) proposition, namely that the vortex will displace a volume $C_M\mathcal{V}$ forward, where $C_M = 1$ for a Lamb's dipole.
On the β-plane the displaced amount of fluid acquires relative vorticity which interacts with the original monopolar or dipolar vortex propagating on the β-plane. Using a similar approach as used for dipoles on an f-plane, estimates for the amount of generated vorticity are made for these vortices moving on the β-plane. The results are applied to give new insight to the effect of vortices in enhancing diffusion, and the secondary flow generated by the transport of ambient potential vorticity.

Mixing and Reaction in Stratified Flow: Lagrangian PDF Methods

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The description of mixing and reaction of species in stratified turbulent flows is of considerable practical relevance. Turbulent mixing processes determine, e.g., the onset of the algae bloom, which is a remarkable problem in the North Sea region. In the atmosphere, the mixing and reaction between emitted nitric monoxide and background ozone has, e.g., a considerable influence on the air quality. The simulation of transport and reaction of species by means of Lagrangian PDF methods offers essential advantages over Eulerian approaches. First, Lagrangian methods are able to describe important processes as for instance chemical reaction without approximations, and to simulate turbulent mixing processes without ad hoc assumptions on entrainment. Second, the structure of these codes is extremely simple, and the number of independent variables may be considerably smaller than in Eulerian closure methods. These advantages of Lagrangian PDF methods will be described and illustrated. Examples are considered related to buoyant flows and the ozone chemistry in the atmospheric boundary layer. Additionally, the results of some first applications of these methods to the algae bloom problem are shown. In particular, it is demonstrated that these methods are well suited to describe the strong variations of the mixing intensity in different stratified turbulent flows.

A NUMERICAL STUDY OF 3D GRAVITY WAVE BREAKING OVER A 2D OROGRAPHY

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Numerical simulations with the nonhydrostatic anelastic model Meso-NH are carried out to reproduce an experiment in a hydraulic tank, realized in CNRM by O.Eiff, of stratified flow past a 2D mountain ridge generating a gravity wave breaking. The simulated dynamics is very realistic compared to the observed one. Particularly, we study why the 2D breaking is unstable with respect to 3D disturbances, leading in the breaking zone to a 3D turbulent dynamics. As soon as quasi stationnary turbulence is reached, we show that 3D eddies have aspect ratios about 1 and the size of the breaking area, whatever the shape of the initial 3D disturbance. We study this 3D dynamics with a spectral method ; in the case of harmonic disturbances, we point out a coherent production of harmonics mainly due to the non linear term of tranverse advection. We conclude that this 3D dynamics is featured by some aspects of classical thermal convection, and seems to evolve quite independently from the 2D wavy dynamics, as soon as the latter has produced convective instability in the breaking area.

INERTIA-GRAVITY WAVES IN THE LOWER STRATOSPHERE: OBSERVATIONS AND RAY-TRACING

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In 1994, a wind lidar was installed at the Observatory of Haute-Provence (south of France) by the Service d'Aéronomie. Specially designed for the study of mesoscale dynamics in the upper-troposphere lower-stratosphere region, the lidar provided regular data since this time. One of the most striking feature of these observations is the quite continuous presence of inertia (low-frequency) gravity waves with amplitudes which can reach up to 10 ms^{-1}. Such waves may induce large isentropic displacements due to their low-frequency and high amplitudes and then be a source of stratospheric-tropospheric exchange.
In order to determine the mechanism which could generate those waves, a 3D model of ray-tracing for inertia gravity waves was developped, which take into account the different characteristics of tropopause disturbed situations (non-stationarity, strong wind gradients). Backward simulations were made with atmospheric fields coming from the ECMWF T-106 model and wave spectral parameters estimated on the lidar data.
The simulations show a preferred backward propagation to tropospheric jet exit region on the west flank of cut-offs low, which result from baroclinic activity in the upper-troposphere. In those regions, the flow is strongly ageostrophic and may excite inertia-gravity waves through geostrophic adjustment.

MIXING IN THE MIDLATITUDE'S WIND-DRIVEN OCEANIC CIRCULATION: DYNAMICAL PROCESSES AND VARIABILITY

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We study transport and mixing in the midlatitude ocean's wind-driven circulation, using a 3-layer eddy-resolving quasi-geostrophic model. By applying dynamical systems theory, mixing processes across the eastward jet between the ocean's cyclonic and anticyclonic gyre can be geometrically represented as the Lagrangian dynamics of the invariant manifolds that define the boundary between them; mixing rate is computed explicitly. Our techniques are also applied to examine regional mixing processes within each gyre, i.e., transport between distinct recirculation cells. We also consider the role that mesoscale eddies, so-called rings, play in the inter-gyre and regional mixing processes. Finally, these components are combined to understand basin-scale mixing processes with emphasis on the connection between the wind-driven ocean's variability and the mixing processes.

TRANSPORT ASSOCIATED WITH INTERNAL WAVE REFLECTION AT A SLOPING BOUNDARY

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Recent oceanic observations indicate enhanced diapycnal dissipation rates in the vicinity of bottom topography (e.g. Toole, Schmitt and Polzin, 1997). High levels of mixing and dissipation have also been noted in observations of internal waves incident upon the ocean floor, (Eriksen, 1982, 1985). When incident waves propagate in an oblique (non-normal) plane, a mean flow will be generated in the cross-slope direction. We investigate the phenomenon of internal wave breakdown, the characteristics of the generated mean flow and the resulting transport by means of high-resolution, 3-D numerical simulations. In particular, we examine the role of wave frequency, intensity and direction of propagation in the breakdown process for a variety of slope angles. The effect of the earth's rotation is also considered.
This study extends the results of Slinn and Riley (1996, 1997) and constitutes the first attempt at numerically simulating the incidence of oblique waves on sloping boundaries.

SUPPRESSION OF VERTICAL DIFFUSION IN STABLY STRATIFIED TURBULENCE

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A simple spectral approximation which may explain a mechanism of the suppression of the vertical turbulent diffusion of passive scalar in stably stratified turbulence is presented.
For strongly stratified turbulence, the turbulent velocity field is well approximated by a collection of Fourier modes (waves) each of which has its own frequency depending on the direction of the wavevector. The proposed approximation suggests that the phase mixing among the Fourier modes having different frequencies causes the decay of the Lagrangian two-time velocity autocorrelation that determines the vertical diffusion, and this mixing results in the suppression of single particle diffusion in the vertical direction. The suppression can occur in the absence of strong horizontal turbulent mixing and the reduction of the magnitude of the vertical velocity component.
The approximation is free from any ad-hoc adjusting parameter and shows that the suppression depends on the spectra of the velocity and fluctuating density fields. It is in good agreement with direct numerical simulations for strongly stratified turbulence.

EXPERIMENTAL STUDY OF LATERAL DOUBLE DIFFUSIVE CONVECTION

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Formation of convective current is investigated by optical (schlieren- and dyeing) and probes methods. Affects of sloping heat front and initial density gradient value on the rate of the formation and scales are studied. The basic structure elements of convection (split boundary current, cells, heat front, dissipative gravity waves) are studied. The pattern of the diffusion induced boundary current on a sloping plane- is visualised. Mean height of the cells correlates with the natural scale of the adiabatic ascent of heating liquid element. The proportional coefficient value is measured under different sloping angles of the heater. Rate of the structure formation is a nonmonotonic function of the heat front inclination angle. With increasing of a buoyancy period process is delayed. The front velocity weakly depends on external parameters of the problem. Hight of dissipative gravity waves is defined. Experimental data are compared with results of Lie groups and asymptotic treating of the problem. An extrapolation of results on natural conditions and comparisons with observations in atmosphere, ocean and some technological processes are conducted.

RESEARCH OF DISINEGRATION OF INTERNAL WAVES

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The propagation of nonlinear internal gravity waves in stratified gas is investigated. The model is two-dimensional. Analytical models show that internal waves can disintegrate into solitary waves of well smaller scales. The waves formed are eddies in essence. The sizes of formed waves can be extremely small. It depends on an initial wave form and on a stratification. It is possible to interpret these processes as mixing. The analytical outcomes are not quite strictly proved yet. They require independent confirmation. Besides, it is interesting to simulate wave disintegration with the help of direct integration of hydrodynamic equations. The special numerical model using hydrodynamic equations, is developed. The outcomes of numerical simulation are compared to analytical ones. The satisfactory coincidence of analytical and numerical outcomes is revealed.

ANELASTIC MIXING: TRANSPORT BY WEAKLY COMPRESSIBLE FLOW

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Many studies to date have focused upon the turbulent diffusion of a passive scalar in the presence of an incompressible fluid flow. This is quite natural as a means for understanding mixing in turbulent environments for which the fluid in question satisfies a zero divergence constraint. However, for many physical environments, the fluid density is not constant, and may admit a non-trivial adiabatic steady-state density profile leading to non-zero flow divergence constraints. Such is the case when considering the atmosphere over moderately large vertical scales.
Here, we discuss a simplified model aimed at describing fluid flow in the presence of large-scale density variation. We then derive effective equations governing the large-scale, long-time renormalized dynamics of a passive tracer diffusing in the presence of this weakly compressible fluid flow. We compare the predictions of this theory with the analogous theory of homogenized enhanced diffusivities for the constant density case and demonstrate some interesting differences in the effective bulk transport of the scalar quantity specifically due to the combined effects of the variable density profile and small-scale fluid motion.

EXPERIMENTAL STUDY OF INTERNAL SOLITARY WAVES BREAKING ON A SLOPE

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Long internal waves, primarily generated by tides in the ocean, propagate on the thermocline into the continental margins and coastal zones. In lakes such waves are generated in response to strong wind events and are an important means of energy transfer from large scales down to small.
The shoaling and breaking of an internal solitary wave of depression were experimentally studied. The waves were generated with as large an amplitude as possible in order to maximize the amount of energy involved in the experiment. Various bottom slopes, thickness ratios and density ratios were investigated.
The mechanism leading to breaking is examined with the support of photographs and a PIV technique. Since the layer thickness ratio primarily controls the length (L_W) of the solitary wave (for a given amplitude a), it is found that the ratio of L_W over the length of the slope determines the amount of energy reflected from the slope. The estimation of the increase of the potential energy allows us to compute the mixing efficiency of the breaking event.

STATISTICAL ANALYSIS OF THE SURFACE CIRCULATION IN THE ALGERIAN CURRENT USING ARGOS BUOYS

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A kinematic description of the surface circulation in the Algerian Current is presented using the statistics of 3 months of trajectories of 17 satellite-tracked drifters. The drifters were released upstream and across a coastal meander, between 0° and 1° E of longitude. They traveled eastward with an average speed of 9-10 cm/s along the Algerian coast through an inhomogeneous field of mesoscale eddies (20 cm/s average fluctuation speed). The Lagrangian time scales are Tu, Tv=2.63, 1.44 days and Lagrangian space scales Lu, Lv=48, 23 km. The computation of single particles dispersion is used to prove the validity of the theory of diffusion by homogeneous random motion (Taylor's, theory) to describe these dispersive motions.

INTERACTION OF WAVE-LIKE DISTURBANCES WITH HELICAL TURBULENCE IN STABLY STRATIFIED PLANETARY BOUNDER LAYER

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Interaction of wave-like disturbances with helical turbulence in planetary boundary layer is studied theoretically for the case when vertical shear of mean gradient wind is sufficient to reach near-threshold value of gradient Richardson number based on this shear and on the buoyancy frequency determined by mean density stratification. It is shown that in this case small-scale helical turbulence in the boundary layer can cause instability of wave-like structures with vertical scales intermediate between those of turbulent vortices and thickness of the boundary layer and with much larger horisontal scales. In their turn these structures can enhance the turbulence leading to the process of helical wave-turbulent instability. Such a process may take place in the region of large horisontal pressure gradients around developing tropical cyclones. The work was partially supported by INTAS under grant 93-1194-ext. and by RFBR under grant 96-02-19506.

MIXING IN A STABLY STRATIFIED SHEAR LAYER

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We have investigated the mixing properties of a stably stratified shear layer in two and three dimensions, using a new analysis of mixing. Previous analysis of mixing rely upon the advective flux of density, whereof oscillations are filtered out by a temporal average in order to get the irreversible contribution associated with mixing. The new analysis we employ is based instead upon the direct computation of the diffusive flux of density.
We shall show that, when the dynamics are strongly nonlinear, only the novel analysis is able to provide estimates of mixing efficiency. When the vertical scales of the flow collapse and a weakly nonlinear regime is reached, predictions by the analysis based upon the advective flux become possible and coincide with those by the new analysis. The link between mixing and the flow dynamics is quantified by a normalized turbulent diffusivity as a function of a Froude or a Richardson number. We shall show that the same law is obtained whether breaking waves or a stably stratified shear layer are considered, and this is consistent with the latter flow being a local physical model of the former. This result has important implication as regards to parameterization of small scales in large scale geophysical models.

CLIMATOLOGY OF INTERNAL GRAVITY WAVES IN A STABLY STRATIFIED ATMOSPHERIC BOUNDARY LAYER

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Internal gravity waves transport energy and momentum in the atmospheric boundary layer. Under stable conditions they can significantly influence the dispersion of pollutants. Thus it is of interest to investigate their properties and the conditions under which they occur. Throughout 1991, the British Antarctic Survey made an extensive set of boundary layer observations from their research base at Halley, which is situated on the Brunt Ice Shelf, Antarctica. Wave-like fluctuations were frequently detected. Since gravity waves at the surface are most readily detected via pressure measurements, an array of six microbarographs was designed specifically to operate under the extreme climatological conditions prevalent in the Antarctic. Microbarograph observations were supplemented with measurements from an instrumented 32m meterological mast. A beamsteering technique was used to determine wave parameters from the microbarograph data. A climatology for the gravity waves will be presented. Such information is central to the evaluation of the statistical influence of gravity waves on boundary layer dynamics.

EFFECTS OF DIRECTIONAL SHEAR WIND ON GRAVITY WAVE DRAG

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A mesoscale 3D non-hydrostatic, non-linear model (NH3D) was used to investigate the effects of directional shear wind on orographic waves. Parametrizations of Gravity Wave Drag (GWD) do not take into account the turning of the wind with height, which can be greater than 120° in the very stably stratified Antarctic boundary layer during winter. Our numerical simulations with idealised orography and wind profiles have revealed that this effect can be relevant in several situations. When wave breaking occurs in directionally sheared flows, it is spread in the directions spanned by the wind, and extreme high drag states are moderated. On the other hand, with directional shear, transitions to low drag states are delayed and time variations of the surface drag are smaller. For flows with Froude number $Fr = U/Nh \approx 1$ (U - wind magnitude, N - stability, h - mountain height) or slightly greater, directional shear induces higher drag states than unsheared wind profiles. The numerical results also show that the magnitude of the surface drag decreases when the depth of the directionally sheared layer increases. This result is specially relevant in the Antarctic, where the depth of the sheared layer is of order 500m. A comparison between these numerical results and linear theory will be presented . Our results indicate that directional shear effects should be included in GWD Antarctic parametrizations.

STABILITY AND ROLLOVER IN DOUBLE DIFFUSIVE SYSTEMS

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Double diffusive systems, by which we mean bodies of moving or stationary fluid subject to temperature and concentration gradients, occur in both natural and man-made systems, such as the oceans and liquid natural gas storage respectively. Associated with double diffusive systems is the phenomenon of rollover, in which two adjacent layers of liquid become equal in density and mix rapidly, potentially causing a release of vapour pressure from the lower layer. A double domain spectral Chebyshev code has been written to simulate the convective flow of a fluid in a finite domain approaching rollover. The initial stable state is a fluid layer of low species concentration overlying a layer of greater concentration. The body of fluid is subject to heating both from the side and the base. Cooling occurs at the top. Event ually the densities of the layers become equal and rollover occurs. Various temperature Rayleigh numbers are considered, and the simulations take place within the laminar regime.
Within such convective systems are regions of shear, which can be simply regarded as stably stratified double diffusive Couette flow. We have obtained neutral stability curves for the linear theory of such flows. Centre manifold theory and two time scales have been used, in conjunction with the vertical modes of the linear theory, to derive a wave evolution equation in the sheared layer.

NP3 Transport and mixing in geophysical flows

Convener: Legras, B.

02 Turbulence and mixing in geophysical flows, effects of stratification and rotation, convection, effect of coherent structures, Lagrangian chaos

Convener: Redondo, J.M.

NONGAUSSIAN PROBABILITY DENSITY FUNCTIONS OF SMALL-SCALE FLUCTUATIONS IN THE STABLY STRATIFIED ATMOSPHERE

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We present experimental results about the probability density functions (PDFs) of temperature and horizontal velocity small-scale fluctuations in the stably stratified atmosphere using a data set composed of vertical profiles of energetic atmospheric variables obtained by a balloon-borne instrumentation. Vertical profiles of temperature and velocities small-scale fluctuations in the stable, free atmosphere usually show a characteristic pattern of strong signal amplitude regions alternating with quite calm areas. Within strong signal amplitude regions, energy spectra versus vertical wavenumber m often scale like $m^{-5/3}$in the metric wavelengths band, thus suggesting a turbulent inertial subrange, *à la Kolmogorov*. Somehow less known is the fact that in the free atmosphere, calm areas show energy spectra scaling like m^{-3}, down to the instrumental noise level. We consider fluctuations in the spectral band $[2m - 20m]$. We then show that, for horizontal velocity, a same PDF shape of normalized fluctuations is associated with a given dynamical regime (turbulent or calm), but differs from the shape of the PDFs of fluctuations in the other regime. For temperature, a same shape of PDF is obtained for both regimes. All those PDFs are nongaussian, with tails scaling like $\exp^{-\beta|x|^c}$, $c \simeq 1$.

THREE-DIMENSIONAL INSTABILITY OF ANTICYCLONIC BAROTROPIC VORTICES IN A ROTATING FLUID: LABORATORY EXPERIMENTS

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Ambient rotation can be a crucial factor for development of instability of small and meso-scale vortices in the oceans and atmosphere and the subsequent transition to turbulence. New results from a sequence of especially designed laboratory experiments that focus on the instability of swirling anticyclonic flow will be presented. The flow is created by a cylinder rotating in a fluid which is itself initially in a state of solid-body rotation. The experiments demonstrate that secondary motions with a well defined wave number appear in an annular region surrounding the cylinder and are governed by the process of three-dimensional centrifugal instability. The evolution of the secondary motions gives rise to the appearence of tertiary motions - which are Kelvin-Helmholtz like vortices that develop at the periphery of the annulus, thus creating a complex three-dimensional structure in the unstable flow. If the rotating cylinder is withdrawn vertically from the fluid, the instability rapidly destroys the core of the vortex in a way that is consistent with the behaviour of unstable vortices observed in previous laboratory experiments by Kloosterziel and van Heijst (J.Fluid Mech., 223, 1992). The results of the experiments will be compared with the results of recent numerical stability analyses by Smyth and Peltier (J.Fluid Mech., 265, 1994) and Potylitsin and Peltier (J.Fluid Mech., in press, 1997).

MIXING LAYERS IN NATURE STREAMS.

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Period of coherent oscillations of velocity field in plane mixing layers in nature streams is investigated. Two different mixing layers are considered: (i) at the lower surface of the ice-covered flow in the Lake Baykal which is induced by the overflowing Angara River (u=6m/s) and (ii) the flow behind the bottom sand wave in the River Polomet (h=0.4m, B=25 m). Since the mean velocity profiles of the mixing layers (i) and (ii) have the inflection point, the flows in these layers are hydrodynamicaly unstable. The quasi-periodical character of the mixing layer is accompanied by generation of coherent vortex structures. The period of oscillation of mixing layer is calculated in a model of the plane mixing layer by solving probability averaged Navier-Stokes equation. The total viscosity which is the sum of turbulent and molecular viscosity, the pressure gradient and the initial velocity ware assumed to be constant and solution of the N-S eq. was obtained. The calculated profiles of mean velocity are in good correspondence with the measured ones. The analysis of this solution shows that the product of the dimensionless period and the total viscosity is constant. This fact is used to calculate the period of oscillation of the mixing layer. The result of calculations for the oscillation period of the mixing layer in the flow (ii) was shown to be in good agreement with the value obtained by measuring of spectrum functions of velocity fluctuations.

AN EVALUATION OF THE ASYMMETRY OF TURBULENCE IN THE ATMOSPHERIC BOUNDARY LAYER

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The aim of this work is the definition of some mathematical tools for the evaluation of the spectral and spatial asymmetries present in atmospheric turbulence. To this purpose, using the non local formalism of Transilient Turbulence Theory, five indicators of asymmetry are introduced. They are able to quantify the global amount and the configuration of the asymmetry between the spectral composition of upward and downward motions.
A conservation property is demonstrated, that allows one to calculate, in the framework of Transilient Turbulence Theory, a basic state of turbulence that does not depend on the symmetry properties of the configuration but only on the total amount of turbulence. This invariant is used to normalize in a coherent way the indices of asymmetry here proposed.
These indicators are applied with good results to ideal test cases and to transilient matrices obtained with Large-Eddy Simulations by Ebert, Schumann and Stull for convective and neutral Atmospheric Boundary Layer.

THE EFFECTS OF MARKOVIAN RANDOM FORCING AND DISSIPATION IN 2-D TURBULENCE

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Results from over 500 high-resolution (up to 1024×512 grid-size), direct numerical simulations of 2-D incompressible turbulence, with prescribed random forcing, in spherical geometry are presented. Through a systematic exploration of the numerical and physical parameter space, it is found that the inertial range slopes can assume a range of values; the $-5/3$ value of the inverse cascade range corresponds to only one set of simulation parameters, and hence is not universal. In the physical space, the forcing generally overwhelms the flow, restricting the size, coherence, and mergers of the vortices that emerge for a wide range of amplitudes, scales, and correlation times (i.e., correlation times long and short compared to vorticity injection timescale). In the case with rotation, the latter behavior produces a flow that does *not* correspond too closely to observed planetary flows; a more physical forcing, one that interacts in turn with the generated flow, is required for geophysical and planetary applications.

STRONG TURBULENCE AT AN AIR-WATER INTERFACE.

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Building on the work of Brocchini & Peregrine (Proc. Conf. on Wind-over-Wave Couplings: Perspectives and Prospects, Inst. Maths. and its Applic. Salford, Oxford Univ. Press , 1997) interactions of strong turbulence with an air-water interface are analysed. These can be particularly relevant to predict momentum and heat fluxes across the sea free-surface. This is particularly true when turbulence is so strong to lead to the 'splashing' regime characterised by violent mixing of gas and liquid. A range of flow regimes is inspected to derive a proper scale-dependent description of the interactions. Increasing turbulent intensity leads from a smooth surface first to a rippled surface then clearly developed micro-breaking. Further increases in turbulent intensity lead to air entrainment and drop formation giving a bubbly flow; eventually highly energetic turbulence leads to a splashing regime. A common, yet poorly studied, flow regime is analysed in which surface deformations caused by patches of turbulent flow occur in the shape of 'scars' (hence 'scarified' flow). A simple description of the water flow regimes is given in terms of only two main parameters. The first is a typical length λ representing either the size of the turbulent eddies or coherent patches of vortical flow. The other variable used in this discussion is the local turbulent kinetic energy density k defined in terms of the turbulent fluctuations u_i as: $k = \frac{1}{2}\langle u_i u_i \rangle$ where $\langle . \rangle$ is the ensemble average operator. The stabilising effects of both gravity and surface tension are analysed in the (λ, k) plane which is also used to characterise the typical behaviour of each flow regime.

COHERENT STRUCTURES IN ICE COVERED SHALLOW FLOWS.

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The purpose of the work is the attempting to explain the nature of ice covered flows in shallow currents with non-linear system in nonequilibrium condition and to show that non stability of the motion is connected not only with streamlining of two solid roughness surfaces but with interaction of two boundary layers in a central region of the current.
Numerous measurements show that in natural ice covered shallow current we can meet the situation when two boundary layers are crossed more often. In this case the picture of current is different from flow in tube with equal roughness. The mixing layer appears on crossing boundary of layers streamlining the surfaces with different roughness. This mixing layer is characterised by bend point on vertical profile of mean velocity. It is obviously that non zero turbulent shear stress (large Reynolds numbers) and broad spectrum of velocity fluctuations must correspond to this region of non stability. To test this supposition we measured the fluctuations of longitudinal velocity in ice covered flow at rivers Moskva and Desna.

MODELLING CONVECTION IN THE MEDITERRANEAN SEA WITH DIFFERENT TURBULENCE CLOSURE SCHEMES

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In this numerical study, the effect of different turbulence closure schemes for parametrizing shallow and deep convection on intermediate and deep water formation in the Mediterranean Sea is investigated. An annual cycle (year 1987) including realistic forcing (ECMWF) is simulated for the whole Mediterranean Sea by means of an OGCM using four different turbulence closure schemes: (i) the k-ε model, (ii) the Mellor-Yamada level 2.5 model (MY), (iii) the Deardorff [1983] bulk model and (iv) simple convectional adjustment combined with constant background viscosity/diffusivity. Two sites are investigated in detail: (i) the Gulf of Lions (deep convection) and (ii) the Rhodes gyre (shallow convection). For these sites, comparative experiments with one-dimensional models are carried out. It is shown that the 1D and the 3D models give similar results if the same surface forcing is used and some corrections for advection of heat and salinity are applied. The vertical structure of the water column calculated with the k-ε and the MY model is nearly indistinguishable due to the similar structure of the models. The other two, more simple models give sufficient results for the water formation rates, but do not provide information about the structure of the mixed layer.

Vortex structures in stably stratified rotating fluids

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A stable linear density gradient supports a horizontal baroclinic torque that promotes "layering" and a tendency for horizontal alignment of the vorticity vector. The internal Froude number Fr=U/ND gives a measure of the relative importance of the buoyancy forces, for Fr<1 there is very little vertical motion and the flow is quasi 2D in nature. Uniform background rotation promotes a vertical alignment of the vorticity vector when the Rossby number Ro=U/fD is small. Rotation tends to increase vertical coherence of structures while stratification confines structures to weakly correlated layers. By exploiting the inherent anisotropy associated with low Froude number flows a stack of horizontal slices is sufficient to fully reconstruct the 3D vorticity field. Large vortices created in the 13 meter diameter rotating platform Coriolis gain their Reynolds numbers from their size and have very long turn-over times. These long time scales permit the effectively instantaneous acquisition of relatively large numbers (50) of horizontal image slices. Full 3D vorticity fields are obtained in time using the Correlation Imaging Velocimetry (CIV) technique. The vortex dynamics is captured and parameterised as a function of the Reynolds, Rossby and Froude numbers.

EFFICIENT REPRESENTATION OF COHERENT STRUCTURES BY TRANSLATION-INVARIANT ORTHONORMAL WAVELET ANALYSIS

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Wavelet analysis (WA) techniques have been applied to an increasingly varied range of geophysical fields over the past few years. A 'problem' with the standard orthogonal WA has been observed, and sometimes caused strenuous objections. WA is *not* translation-invariant, unlike Fourier spectra. Thus the position of a spatially localized feature, such as a coherent structure, can drastically alter the distribution of WA coefficients over scale and position, introducing a kind of spurious scale coupling. A remedy for this is the *orthogonal translation-invariant WA*, which selects an optimal new origin (*"best shift"*), regardless of the 'original' origin. For instance, in an atmospheric block structure, from 60% to 90% of the isobaric height variance is explained by just 1 to 3 wavelet coefficients, after applying the best shift.

TRANSPORT DURING A STORM LIFE-CYCLE IN A SIMPLIFIED GCM

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We study tracer transport during a baroclinic life-cycle. An individual life-cycle has been isolated by introducing a small perturbation with fixed wavenumber in the Eulerian ground pressure field of a stationary baroclinic state of a simplified GCM. The trapping and detrapping properties of individual storms are examined and compared with the behavior of barotropic and baroclinic quasi-geostrophic vortices. The presence and the properties of transport barriers is addressed, and the role of diabatic effects is explored by comparing 2D and 3D simulations.

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OCEANOGRAPHIC IMPLICATIONS OF WAVE-INDUCED TURBULENT DIFFUSION

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Based on a recently developed theory of turbulent diffusion by random waves, we present estimates of horizontal diffusion coefficients for passive scalars for two types of wave motions - baroclinic inertia-gravity (BIG) waves and wind-generated surface gravity waves on deep water. The wave diffusion effect, though only of second order in the wave amplitude, is comparable to the diffusion caused by random fluctuations in the Stokes drift in nonlinear waves considered earlier by Herterich and Hasselmann. The BIG wave induced diffusion is shown to be negligible compared to the usual, eddy-induced diffusion on the largest scales. However, its relative importance increases at smaller scales (~ 10km) and it may therefore significantly affect the subgrid diffusion constant used as input to eddy resolving ocean circulation models with mesh sizes on this scale.

NONLINEAR FEATURES OF ROSSBY WAVE PACKET PROPAGATION ON THE β-PLANE

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We consider rays of propagation and the local wavenumber evolution of quasi-geostrophic barotropic Rossby wave packets on the β-plane. The equations governing the evolution of the local wavenumbers and the propagation paths of the wave packets are obtained from the dispersion relation which is derived by substituting a WKB-ansatz into the linearized potential vorticity equation. For particular basic flows, the wavenumber equations can be decoupled from the group velocity. It is known that even in such simple situations oscillations and bifurcations can be found in the so called wavenumber phase space. We vary the problem by applying more general basic flows where a decoupling of the wavenumber equations from the wave packet path is not possible. In that case the solutions depend strongly on the parameters of the model and can also be chaotic. Preliminary results of different experiments will be presented.

JETS IN FULLY DEVELOPED BETA-PLANE TURBULENCE IN A MULTI-LAYER MODEL

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Jets are a frequently occurring feature of many large-scale geophysical flows and have the important property that they tend to inhibit transport of fluid and tracers across the jet, therefore acting as barriers to transport. This property may be important in natural contexts such as the tropopause and the North Atlantic Gulf Stream. These examples also show strong vertical variations in cross-jet transport.
As a paradigm for jet structure and cross-jet transport, forced-dissipative systems have been examined in which the forcing represents a relaxation to a baroclinically unstable state. Panetta (1993) showed how multiple zonal jets develop in a two-layer, quasi-geostrophic, beta-plane system. Held & Larichev (1996) gave a partial explanation for these results using scaling arguments and proposed a scaling for the equivalent continuously stratified system.
The study reported here uses a multi-layer (equivalently, continuously stratified) model to examine the jets. The transport properties of the jets are analysed using a combination of particle and tracer analysis. The results are compared with Held & Larichev's scaling arguments, and the vertical structure of the jets and the mixing is examined. Implications for atmospheric and oceanic flows are discussed.

AN ENSEMBLE APPROACH TO PREDICTING CHEMICAL EVOLUTION IN CHAOTIC ADVECTION FLOWS

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A theory will be presented for predicting the evolution of chemical systems where the reacting species are initially separated and brought together by stirring and mixing in chaotic advection flows, i.e., flows where the large-scale velocity dominates the stirring. This therefore includes large-scale atmospheric and oceanic flows where effects of stratification and rotation dominate.
The theory is based on considering the system as made up of a large number of elements, each of which experiences a different stretching history. For each element the chemical evolution is predicted by considering a canonical model problem, which is just the chemical evolution in the absence of stretching, except that the time is not real time, but an effective time that depends on the stretching history. The chemical state of the whole system at any real time is predicted by averaging over a large number of realisations of the canonical problem, each evaluated at a different effective time. The distribution of effective times is consistent with the distribution of stretching histories in the flow.
Predictions from the theory are compared to explicit simulations of a range of different flows, from simple shear flows to chaotic advection flows, and theory and simulation show good agreement.

PARAMETERISATION OF THE SEDIMENT STRATIFICATION EFFECT ON FLOW DYNAMICS

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There is much evidence that von Karman's constant in a sediment-stratified turbulent flow decreases with increasing suspended sediment concentration. This variability is apparent and represented nothing else than a consequence of the influence of sediment stratification on the mean velocity if the latter is approximated by the logarithmic law. However the concept of "the variable von Karman constant" may find application as a convenient way of parameterising the effect of suspended particles on flow dynamics. We present the dependence of von Karman's constant on the external parameters determining the vertical structure of the sediment-bearing flow using, as the basis, a k-l model for the steady, horizontally uniform, sediment-stratified bottom logarithmic layer in which the reference level and reference sediment concentration are considered to be dependent on the excess shear bottom stress.

KINEMATIC SIMULATION FOR STRATIFIED FLOWS

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Kinematic Simulations (KS) are Lagrangian models of dispersion that incorporate turbulent-like flow structure in every realisation of the Eulerian velocity field. Individual trajectories integrated in individual KS Eulerian flow fields are therefore smooth and comparable in character to experimental trajectories seen in nature and the laboratory. Lagrangian statistics are taken over many realisations of Eulerian flow fields. We present a modified version of KS in order to model dispersion in stratified turbulent flows, with this new version we can predict, in agreement with experimental and direct numerical simulation results, the confinement of particle dispersion in the direction of stratification. The modelling of dispersion in stratified flows is a delicate balance between dispersion features in a quasi 2-D flow ($x-y$ plan) and dispersion features in the direction of stratification (z direction). To relate these dispersion features to the topological properties of the flow we investigate 2-particle dispersion in each direction and compare the dispersion laws to previous results obtained for two and three dimension flows. We also investigate the dependence of the 2-particle dispersion on the power law of the energy spectrum $E(k) \sim k^{-2p}$ of the velocity field used in the KS simulation. Among other results, we can show the limit of the locality assumption for 2-particle dispersion in stratified turbulence.

THE BREAKDOWN OF CYCLONE/ANTICYCLONE DEGENERACY IN JUPITER'S ATMOSPHERE: MODELING OF CLOUD MORPHOLOGIES BY LAGRANGIAN PASSIVE TRACERS

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Clouds associated with Jovian anticyclones are tight and elliptical while those of cyclones are filamentary and time-dependent. This has been used to argue that the controlling dynamics on Jupiter must distinguish between cyclones and anticyclones (and thereby rules out quasi-geostrophic (QG) models which treat them degenerately). It was argued that the filamentary clouds of cyclones cannot be the signature of coherent, long-lived vortices and therefore that 90% of Jovian vortices are anticyclones, but this confuses instantaneous streamlines with particle paths. Using the weakly-forced, weakly-dissipated QG equation we calculate statistically-steady vortex streets with a forcing that mimics convective overshoot from an underlying convection zone. Clouds act as Lagrangian passive tracers, but they are created in regions of upwelling (anticyclonic vorticity) and destroyed in regions of downwelling (cyclonic vorticity). Thus the clouds themselves break the cyclone/anticyclone degeneracy although the QG dynamics do not. For a small set of parameters both types of clouds are consistent with those of Jupiter. This puts bounds on the amount of turbulence, the magnitudes of the vertical velocities, and the strengths of these vortices, none of which have been previously measured directly.

EFECT OF TEMPERATURE AND SALT STRATIFICATION ON TURBULENT MOTION

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Non-homogeneities of temperature and salinity distributions are responsible for the specific behaviour of perturbations in ocean. This is most pronounced at small-scale interval, in which the distinction of the rates of the molecular temperature conductivity and salt diffusion can cause the anomalous behaviour of the perturbations.

In the report two regimes of motion are considered. The first is the regime of developed turbulence, in which the inertial interval exists. The spectrum of the refractive index fluctuations in water is studied. New expression of the spectrum is found for local-homogeneous and isotropic turbulence. Its dependence on the dissipation rates of the temperature and salinity fluctuations and dissipation rate of turbulence energy is analized. The parametrization of the rates is performed by using Boussinesq hypothesis. Calculations for particular distributions of temperature and salinity characteristic for some ocean regions showed that the spectrum of refractive index fluctuation can have the binary local extremum. The extremum is conditioned by the different contributions of temperature and salinity fluctuations in refractive index fluctuations and difference molecular coefficient of transfer.

EMPIRICAL ORTHOGONAL FUNCTION ANALYSIS OF ALTIMETRY DATA OF THE ALGERIAN CURRENT: TOWARDS A LOW-DIMENSIONAL DYNAMICAL SYSTEM MODEL.

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ERS-1 and TOPEX/POSEIDON altimetry data of the Algerian current are analyzed in terms of empirical orthogonal function analysis (EOF) or Karhunen-Loëve decomposition. The dynamics of the more relevant modes define a dynamical system which is analized in terms of correlations and mutual information measures. We analyze the possibility of projection of a two-layer shallow water model on the space spanned by the more relevant EOF modes in order to obtain a simple dynamical system reproducing features of the data.

ON THE DYNAMICS AND PATCHINESS OF POLLUTION IN A TURBULENT ESTUARINE FLOW

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We present two simple models (one 2+1 and the other 3+1 dimensional) of transport and pattern formation in a 3 D turbulent fluid. This is achieved via a top down and a template approach. The template is based on the fundamental harmonics of the turbulent velocity field, or, in other words, a global cartoon of the turbulent flow. We study the template using the techniques of chaotic advection and the transport theories of Wiggins and MacKay-Meiss-Percival. These ideas are then applied to the question of how a highly complicated or random dynamical system (turbulent velocity field) can produce order in some sense (eg. patches in a pollution cloud). In particular we look at the transport and pattern formation of pollution in an estuary. We build a simple deterministic model to understand the large scale transport of material and the formation and leakage of patches within the pollution cloud. These mechanisms are of vital importance to pollution problems as these patches have a concentration in excess of the average for the cloud and hence cause the most damage.

LARGE EDDY SIMULATION OF ENTRAINMENT IN PENETRATIVE CONVECTION WITH AND WITHOUT ROTATION

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A Large Eddy Simulation (LES) numerical model is used to investigate convectively driven turbulence with focus on the entrainment process and how it can be influenced by the earths rotation. It will be shown that the model gives a fair representation of the complex flow induced by the unstable surface condition and also of the long term descend of the thermocline, when compared to available data. Further, it is demonstrated that for conditions equivalent to very deep mixing layers, the earth rotation may inhibit the entrainment, by what appears to be a restriction in the size of the roll-cells by a Rossby radius. The conclusions are based on a series of numerical experiments that describe the flow in a rotating containment with a homogenous buoyancy source overtopping a stable stratification. They cover Rayleigh numbers of the order 10^{11}, Rossby numbers $Ro = w_*/(fh)$ from 1 to 0.05 and Richardson numbers $Ri = N^2/w_*^2$ from 1 to 50. The numerical model is non-hydrostatic with a finite volume cartesian grid and a fractional step development, that solves coupled Navier-Stokes equations and thermal transport with a second order accuracy. Subgrid stresses are modelled using a Smagorinsky mixing length.

NONLINEAR STRUCTURES ON SATELLITE IMAGES OF THE BLACK SEA.

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Five years full resolution AVHRR data set analyzed for the Black sea aquatory. Detected wide range of the dynamic phenomena occurred in surface layer - eddies, eddies chains, "like mushroom" currents and other coherent structures, frontal unstability, transversal filaments, convection processes etc. Estimated main parameters of these structures - life time, spatial size, typical velocities. Analyzed season variability of spatial patterns distribution and possible reasons of its generation. Noted an existence of cold self current in west part of the sea and its influence on advection processes. Satellite data compared with "in situ" hydrometeorological measurements.

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PARAMETRIZATION OF TURBULENCE AND ENTRAINMENT IN PENETRATIVE CONVECTION

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The entrainment below a shear-free unstable surface layer may be seen as one generic geophysical flow which involve mixing across stably stratified interfaces and is therefore considered to be a relevant benchmark for mixing models in OGCM's. The set-up is convenient as it highlights the mixing process and thereby the parametrization of the non-resolved processes.
The situation has been studied by many authors, but here we utilize recent Large Eddy Simulation results and laboratory data and a 2-equation turbulence closure model, based on the k-ϵ model, as the basis for a parametrization of convectively induced turbulence and the entrainment across a stable interface. It is demonstrated that the model provides a realistic representation of statistical characteristics of the turbulence in the mixed layer, as e.g. the dissipation, and to some extend also of the vertical mixing that leads to the entrainment.
The calibration cover geometrical scales from laboratory to oceanic scales, Rayleigh numbers of the order 10^{11} and Richardson numbers from 10 to 100.

USING SATELLITE IMAGES TIME SET FOR INVESTIGATION DYNAMICS OF THE BLACK SEA UPPER LAYER

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Satellite data give a possibility of observation investigated aquatory on quasi-regular basis. Analyzed infrared AVHRR images from NOAA 12, NOAA 14 satellites for the Black Sea.
Short time interval (~6 hours) between images allowed to make computer movie. This method of information presentation has some advantages for analysis of sea upper layer dynamics. Mathematical formalization for such information is difficult due to difference in spatial size of typical peculiarities in surface temperature. Presented computer movies demonstrating:
- upwelling generation and its interaction with current jet near Crimean coast;
- complex interaction of the coherent structures in East part of the Black Sea;
- exchange via Bosporous strait;
- general circulation of the Black sea for different seasons. Estimated spatial and kinematics parameters of typical structures.

ON ASYMPTOTIC BEHAVIOR OF A FORCED VISCOUS FLUID

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The nonlinear vorticity equation (VE) is used to analyze asymptotic behavior of a viscous forced incompressible fluid on a rotating sphere. A size of the bounded set that eventually attracts all VE solutions is estimated taking account the dissipation as well as the smoothness and spectral composition of the VE forcing. In the case that the forcing is a homogeneous spherical polynomial of degree n, invariant sets of the VE solutions and location of VE attractors are studied analytically. Symmetric and asymmetric VE responses to such a forcing are discussed, and sufficient conditions for the symmetric VE attractor to be global are given. As an example it is shown that the global VE attractor can cyclically change its structure from a zonal to a blocking-like flow. It is also shown that the attractor dimension of the VE subjected on a sphere to a quasi-periodic forcing is not limited above by the generalized Grashof number and may grow with the polynomial forcing degree. The last result is of meteorological interest, since shows that the search of a small-dimension attractor in the time series of meteorological data is not justified.

DOUBLE-COMPONENT CONVECTION DRIVEN BY THE DIFFERENT BOUNDARY CONDITIONS

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Ideology of conventional double-diffusive convection is generalized to apply directly to the large-scale ocean processes through eddy-double-diffusion—instabilities resulting from the unequal perturbed diffusion gradients forming due to the different boundary conditions. In terms of this ideology, the original problem considered by Welander [Tellus 41A, 66 (1989)] is analogous to the diffusive regime, while the inverse type of stratification (Tsitverblit [Phys. Fluids 9(8) 2458 (1997)]) mimics the finger regime. This latter configuration describes the double-component Langmuir circulation problem (Leibovich [Ann. Rev. Fluid Mech. 15, 391 (1983)]) and, in combination with shear motion (induced, for example, by the horizontal nonuniformity in the temperature distribution), may be relevant to the ocean thermohaline circulation. Decrease of the ratio of the vertical and horizontal diffusion coefficients in this case eventually causes formation of multilayered structures and may affect the criticality of bifurcations. Like in conventional double-diffusive convection, the instabilities are also produced under a combination of the horizontal gradients, and this is demonstrated in application to laterally heated stably stratified systems (Tsitverblit [Phys. Fluids, submitted]). Combinations of the above effects arising when the gradients are applied between two inclined planes and their relevance to the ocean are also discussed.

NP3 Transport and mixing in geophysical flows

Convener: Legras, B.

03 Dispersion in two-dimensional flows, mixing, anomalous diffusion, experiments, models and numerical simulations

Convener: Tabeling, P.

ASYMMETRIC TRANSPORT AND NON-GAUSSIAN STATISTICS OF PASSIVE SCALARS IN VORTICES IN SHEAR

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Transport of passive scalars in a chain of vortices in a shear layer is studied using a model motivated by the quasigeostrophic equation, and a discrete map model. Surrounding the vortices there is a stochastic layer where particles alternate chaotically between being trapped in the vortices, and moving following the shear flow. Transport in the stochastic layer is asymmetric, and the statistics of the passive scalar is non-Gaussian. In particular, there is anomalous advection, and anomalous (non-Brownian) diffusion. The probability density function (PDF) of particle displacements δx, $P(\delta x, t)$, is asymmetric and broader than Gaussian. At large times, P relaxes to a self-similar limit distribution of the form $t^{-\gamma/2} f(X/t^{\gamma/2})$, where $X \equiv \delta x - \langle \delta x \rangle$, f is a scaling function, and γ is the anomalous diffusion exponent. As a result, the moments scale as $\langle X^n \rangle \sim t^{n\gamma/2}$. We present a systematic study of the dependence of the mean, the variance, the skewness, and the flatness, on the parameters controlling the asymmetry of the flow. The PDFs of the duration of flight (motion following the shear flow) events, and vortex trapping events, exhibit algebraic scaling. In some cases, the flights correspond to Lévy flights. The results of the model are compared with recent experiments on chaotic advection and Lévy flights in a rotating annulus.

DIFFUSION OF TRACER PARTICLES IN 2 DIMENSIONAL FLOWS WITH LARGE REYNOLDS NUMBERS

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Apart from molecular diffusion - which is extremely small on atmospheric length scales - there is no intrinsic diffusion in the atmosphere that would lead to the mixing of pollutants. The mixing is caused by the currents themselves and is particularly effective in highly turbulent ones. Here we investigate the properties of this mixing for 2 dimensional currents. First we simulate highly turbulent currents using an approximation along the lines of Grossmann et.al. (cf. J. Eggers and S. Grossmann, J.Fluids A3, 1958 (1991)). Then we treat pollutants as tracer particles in these currents and compute their spreading. We discuss in particular the existence of the so called *turbulent diffusion*.

TRANSPORT OF PROPERTIES BY AN INTENSE VORTEX INTERACTING WITH A ZONAL FLOW OR ROSSBY WAVE

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An intense vortex on a beta-plane transports fluid, heat and admixtures even if there is no mean current. This transport realizes in western direction with a meridional component of the displacement. A vortex moves in more complicate way if it interacts with a mean zonal flow or a Rossby wave field. Numerical simulations show some general features of the vortex transport properties in this case. The potential vorticity gradient of the zonal flow influences the vortex motion besides the pure advective transport. The vortex moves across the flow toward the nearest potential vorticity extreme of the same sign and realizes transport of properties in this direction. Trajectories, which were obtained in numerical experiments with various parameters of the flow, were compared with the observed trajectories of atmospheric tropical cyclones. The main types of the tropical cyclones trajectories may be simulated as a result of an interaction of a vortex with a flow and influence of a beta-effect. The transport properties of an intense vortex may be strongly influenced by the Rossdy wave. Numerical experiments demonstrate that an intense vortex interacting with a plane Rossby wave, can pass to irregular oscillations nearby some equilibrium latitude. An intense vortex under the influence of a beta-effect or interacting with waves or currents usually weakens and decreases its size. It looses fluid particles from rotation around the center through narrow filaments. Thus aside of the transport of fluid a vortex provides the mixing through filament formation.

EULERIAN AND LAGRANGIAN STATISTICS IN POINT VORTEX SYSTEMS

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We study the relationships between Eulerian and Lagrangian statistics in a system of point vortices on the periodic domain. The trapping properties of the vortices are investigated and the ergodicity of the passive particle motion is studied.

HYPERVISCOUS DYNAMICS OF TWO-DIMENSIONAL TURBULENCE

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Two-dimensional turbulence has been investigated by many authors using a hyperviscous operator. This dissipation operator, introduced by Basdevant *et al.* (1983), parameterizes the unresolved subgrid scales. Recent studies by Mariotti *et al.* (1994) and Jiménez (1995) have however put forward spurious effects attributed to this hyperviscous operator. The purpose of the present work is to investigate in detail these effects in comparison with simulations using an ordinary laplacian operator.
For this comparison to be physically meaningful, we first introduce the concept of flows that are "equivalent", from a turbulent point of view. We next proceed to comparison between equivalent flows, either simulated using an ordinary laplacian diffusion or using a hyperviscous operator.
For this purpose, we analyse in detail the topology and distribution of coherent vortices in the flow, by means of an automated vortex census based on a new vorticity criterion proposed by Larchevêque (1993) and studied by Herbert *et al* (1996). We obtain temporal scaling behavior for the several simulated flows. Theses results are analysed in terms of intermittency and are compared both to the scaling theory of Carnevale *et al.* (1993) and the numerical experiments of Marteau (1997).

LAGRANGIAN NUMERICAL MODEL OF A BINARY MIXTURE AND SEGREGATION PROCESSES

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Particle size segregation is a quite evident phenomenon taking place when initially mixed particles with different size, mass density, shape, are subjected to shearing or to any body force such as gravity or centrifugal forces. In debris flows, segregation moves big stones from the bank and the bed towards the free surface and the center of the stream and, by differential transport, to the front of the flood, with important effects on the flow resistance and on the stream evolution. In the present work a numerical model is developed in order to represent the simple particle movements in a binary mixture of spheres flowing over an inclined plane. The main aim is to quantify the stresses and to model of the segregation phenomenon, andto relate the forces acting on the different species to the gradient of concentration, the granular temperature,the tensor of the velocity deformation. It is assumed that the spheres are infinitely stiff; the collisions take place in an infinitesimal time and are only binary. The statistic of particle movements and collisions allows the computation of the profiles of mean velocity, of concentration and of pseudotemperature. The results show a clear segregation of the small particles near the bottom, with big particles floating over them.

DISPERSION OF LIGHT LAGRANGIAN TRACERS IN PERTURBED 2D COASTLINE FLOWS

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Light lagrangian particles, which do not follow the streamlines of the flow, are generally captured in recirculation cells. We study numerically a two dimensional channel flow with a sudden expansion, which can be taken as a paradigm flow in a simple geometry and produces one recirculation zone after the opening. The capture rate of tracer particles of different sizes and densities is computed. Various perturbations are then superimposed to the incoming base flow, and render it time dependent; the effect of these perturbations on the capture rate is studied.

NP3

LAGRANGIAN MODELING OF CROSS-EQUATORIAL AIRFLOW – STOCHASTIC RESONANCE IN A HAMILTONIAN SYSTEM

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A Lagrangian model relevant to the planetary atmosphere is employed to study the characteristics of horizontal cross-equatorial flow of particles subject to nonlinear Coriolis, and mean meridional pressure gradient, forces. The dynamics associated with events of equator-crossing by particles is described by a Hamiltonian system with a bistable potential which has a local maximum at the equator. In the absence of any additional forces this local maximum in pressure prohibits particles from flowing from one hemisphere to the other. When all other (i.e. in addition to the mean meridional pressure gradient) forces are introduced into the system as stochastic forcing, modeled by Gaussian white noise, anomalous diffusion up the mean pressure gradient occurs and particles launched in one hemisphere can cross the equator. Spectral estimations of the crossing events show that at low noise intensity the spectral peak is low, narrow and situated at low frequencies. At large noise intensities the process becomes noise-dominated. Our results demonstrate the existence of an optimal noise intensity where the signal-to-noise ratio of equator crossings exhibit a sharp maximum. These results demonstrate, for the first time, the occurrence of stochastic resonance in a Hamiltonian system.

FLUCTUATIONS OF PARAMETERS OF CONTOURS CARRIED BY A RANDOMLY MOVING INCOMPRESSIBLE MEDIUM

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Analysis of tracer's diffusion in turbulent media is necessary for solution of many problems in physics of atmosphere and ocean, and excites high interest. However, the main attention has been attracted to evolution of tracer's average density or to analysis of single tracer particle's diffusion. At the same time, the investigation of probability properties gives more adequate description of many significant peculiarities of density field.
In this report results have been obtained from a study of the topographical peculiarities of the passive tracer density in a randomly moving incompressible medium. For these purposes the correlations between Lagrangian and Eulerian statistics of fields in turbulent media and formulas, which are connected Lagrangian and Eulerian probability distributions of tracer's density and Jacobian are obtained. On the basis of these formulas the evolution of the length of a contour of a constant tracer density and of the total gradient of the density field are investigated. The expressions for the probability distribution of the total gradient and it's moment functions are derived.

AN EXPERIMENT ON TWO-DIMENSIONAL TURBULENCE IN A MIXING LAYER

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An experiment is performed in a thin horizontal circular layer, in presence of a vertical magnetic field, in conditions such that two-dimensionality is well achieved. An external annulus rotates under the action of electromagnetic forces, the middle part is at rest, and a circular mixing layer develops between them. This mixing layer is unstable and generates eddies aligned with the magnetic field, which interact to transfer energy to larger and larger modes. The central part of the bottom plate may be heated, whereas the external wall is water-cooled, so that temperature behaves as a passive scalar transported accross the mixing layer by this turbulence. MHD also offers a diagnostic technique, via the measurements of electrical potential differences at the bottom wall, which yield core velocity and temperature. Profiles of the most important quantities (mean velocity, temperature, rms of their fluctuations), correlations and spectra are presented. They reveal the main features of this kind of turbulence : a small number of large coherent structures fed by the inverse energy cascade, energy spectra exhibiting peaks at low wave numbers and a small inertial range characterized by either $k^{-\frac{5}{3}}$ or k^{-3} laws, a transport of heat much less efficient than the transport of momentum. It is expected that this well controled experiment may yield data which could be used to validate models and better constrain the behaviour of 2D turbulent geophysical flows.

EVOLUTION OF THE PASSIVE TRACER CLUSTERS IN COMPRESSIBLE TURBULENT MEDIA

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The most distinctive peculiarity of tracer in compressible chaotic moving media is the formation of cluster structure, i.e. the appearance of small regions of high density, surrounding by broad regions of low tracer density. The well known Large-Scale Structure of mass distribution of the Universe is the good example of such kind structure. In this report some models of 1D and 2D compressible media illustrating the arising and evolution of the clusters structure are investigated.
The Fokker-Planck equations for the probability distribution function describing the fluctuations of the clusters width for the cases of 1D and 2D compressible media are derived. It is shown that these equations have the stationary solutions. It means that medium chaotically compressions prevent from molecular diffusion action and lead to the clusters localization in time. The analysis of these equations consequencies allows to find out the peculiarities of arising and evolution of clusters structure.

NEW TWO–DIMENSIONAL MODEL OF POLLUTION TRANSPORT IN BAROCLINIC FREE ATMOSHERE

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Two–dimensional model, which describes large–scale processes, impurity transfer and diffusion in free atmosphere, is derived. This model is the development of shallow water theory for baroclinic atmosphere. Its derivation from three-dimensional equations of a dry atmosphere and equation of transport and diffusion of heavy impurity in local isobar system of coordinate within the static and "β – plane" approximation is asymptotically correct by application of long-wave approach. To close the averaging across layer equations we use the exact solution of the original three–dimensional problem for a linear depending of temperature and geopotencial in the upper and lower boundaries. We investigated the influence of advection to large–scale atmospheric flow circulation and to pollution transport. The aim of our numerical experiments are the evaluate of the weighted particles transport in atmosphere from the large pollution sources of industrial centres in the European part of Russia. The calculating background of impurity concentratiom corresponds to results of observation.

SHEAR GENERATED MIXING PROCESSES IN ARCTIC AND SUB-ARCTIC FJORDS

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There are many preferences by studying small scale phenomenon in fjords compared to similar studies in the open sea. Field experiments, applying high resolving acoustic current meters (UCM-40) and CTD, have been carried out in one arctic fjord (West-Spitsbergen) and two sub-arctic fjords (Troms, North-Norway). The investigations in the sub-arctic fjords was based on current measurements from permanent rigs and a ship operated combined CTD and current meter, while the experiment in the arctic fjord was carried out through a hole drilled in the ice which covered the fjord. The observed temperature, salinity and current showed a strongly varying pattern both in time and space. Characteristic for all the three fjords was the microstructure which appeared in the water column in both the density and the current profiles. The results indicates that shear generated turbulence most of the time is the major source of turbulent energy to the mixing processes in all the three fjords.

NUMERICAL EXPERIMENTS FOR ADVECTION-DIFFUSION SCHEMES : APPLICATION TO LARVAE TRANSPORT IN THE ENGLISH CHANNEL.

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A numerical model of tidal circulation was used to determine the P. flesus larvae advection in the Eastern English Channel. The larvae spatial distribution was observed during April-May 1995. As the vertical distribution of the larvae in the water column was not specified, this enable a preliminary investigation in the framework of a depth averaged model. The model is based on finite differences schemes with splitting up techniques, and uses a finer mesh size. In order to reduce the numerical diffusion in the scalar transport model, we investigate different schemes. Comparisons are made between the upwind and Lax-Wendroff schemes with more recent higher order schemes: Minmod, Superbee, Van Leer and Centred-Monotone schemes. Numerical experiments show that the upwind scheme is excessively damping. The Lax-Wendroff method exhibits better amplitude preservation, but introduces the under and overshoots in the numerical solution. The flux-limiters, when there are Total Variation Diminishing, reduce the numerical diffusion identified in the first order schemes. The Superbee limiter was found to be a good compromise between shape preservation and computational cost in the tracer advection model.

COMPUTATIONS OF IMPURITY TRAJECTORIES IN TWO-DIMENSIONAL INCOMPRESSIBLE PERIODIC FLOWS

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The motion of impurities in two-dimensional, incompressible periodic flows has been numerically investigated, in order to assess the questions raised by previous authors, and to evaluate the importance of the various terms in the law of motion. In the basic case of Stokes drag and inertia forces, it is recognized that light impurities (i.e. impurities whose density is less than that of the surrouding fluid) are captured by the vortex centre, and the time needed to reach the centre is a function of the density ratio and of a time scale typical of particle motion. For both the limits of very high viscosity and of inviscid motion, this convergence time tends to infinity. For heavy impurities the diffusive and ballistic regimes are distinguished, accounting again for a 'divergence' time scale, related to the impurity properties. Furthermore, the effects of Basset memory force, of the lift, and of a different formulation of drag to account for high Reynolds number are discussed for some examples.

NP3 Transport and mixing in geophysical flows

Convener: Legras, B.

04 Biological processes and mixing in the ocean (co-sponsored by OA)

Convener: Richards, K.J.

Interplay of Fluid Dynamics & Plankton Population Dynamics in the Ocean

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Plankton is a collective term describing many species of small (usually 10^{-4} - 10^{-2}m) plantlike, photosynthesising (phytoplankton, P) or animal like, herbivore (zooplankton, Z) organisms. Growth needs a nutrient supply (N), together with available radiation. Striking features of the population dynamics are its spatial and temporal variability. Blooms, in which the population of P (and to a lesser extent Z) increases by 1-2 orders of magnitude in a few days, occur at some times and places, often unpredictably, and spatial patchiness is ubiquitous. Mathematical models range from highly complex, amenable only to numerical simulations, to very simple, allowing the possibility of some analytical understanding and hence predictive properties. Here we report results from simple (NPZ) population models, comprising coupled differential equations of excitable nature. Effects of non-uniform flow fields on the dynamics of these models are explored, both when the plankton is entirely passive, and also when the zooplankton adopts feeding strategies involving relative motion. Implications for blooms and spatial patchiness are discussed.

RELATIONS BETWEEN PHYTOPLANKTON AND TRACE METALS

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Laboratory experiments were conducted in order to describe the main interactions between phytoplankton and trace metals in the column water of the Gulf of Lions. Two marine microalgae present in this environment, the prymnesiophyte *Emiliania huxleyi* and the diatom *Leptocylindrus danicus*, were grown in two axenic seawater medium : (1) the F/2 medium and (2) a seawater-like trace metals concentrations. The aim of these experiments is to investigate the trace metals (Cd, Cu, Fe and Zn) distribution between the dissolved and the particulate phases for these two species at the different steps of the algae growth, in the two medium. On the contrary *of Emiliania huxleyi*, the growth rate of *Leptocylindrus danicus* is maximum in the medium enriched in trace metals (F/2). Lower trace metals concentrations of the second medium induce a decrease with a factor 2 and 3 of the Chl *a* levels for *Leptocylindrus danicus* and *Emiliania huxleyi*, respectively. These experiments will allow us to determine the distribution coefficient Kd, the relation between the phytoplankton and particulate trace metals. Results will be included into the 1D water column model (Tusseau et al., 1997) currently modified to describe the fate of these trace metals in the column water in relation with the organic matter. (This work is part of the E.U Metro-Med Project (MAST3-CT96-0049)).

THE PHYTO- AND ZOOPLANKTON FIELDS OF THE ATLANTIC OCEAN.

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Data from 20 years (1970-1990) of expeditions to the Atlantic Ocean are summarised in the form of macroscale contour maps. The chlorophyll *a* concentrations from surface and mesozooplankton in the upper layer (0-100m) were analysed from 3000 and 1300 casts respectively. General agreement between chlorophyll concentrations and mesozooplankton biomass distributions was noted on an ocean basin scale. The comparison of chlorophyll concentration within the surface layer for some cruises and CZCS data was made for individual provinces. For the open ocean there was significant correlation between *in situ* measured and satellite derived chlorophyll concentration. There was a linear relationship between mean chlorophyll concentration within the 0 to 10 m layer and mesozooplankton biomass within the 0 to 100 m layer for 9 biogeochemical provinces for summed data between December to May and June to November. For certain provinces relations were established between primary production, phytoplankton and zooplankton biomass. Biomass of phytoplankton and zooplankton were estimated for the biogeochemical provinces of Atlantic Ocean. The total biomass of phytoplankton was estimated at 100 mln t C, and that of mesozooplankton at 65 mln t C.

NP3

EFFECTS OF ADVECTION, MIXING AND SINKING ON SPATIAL AND TEMPORAL EVOLUTION OF BIOCHEMICAL PARAMETERS IN THE MEDITERRANEAN SEA

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In the Mediterranean Sea, average fluxes of matter have opposite directions in the upper ocean, one being eastward oriented and the intermediate one, controlled by LIW, westward. As a consequence fluxes caused by advection, mixing and sinking velocity of particulate matter, strongly affect horizontal spatial distribution and play a major role in giving rise trophic gradient. In this communication, we investigate the effect of sinking velocity on spatial and temporal evolution of biological parameters. Also the influences of advection and mixing are analyzed. Numerical results are obtained with a three-dimensional hydrodynamical ecological model, using a lumped variable description of the first trophic level, while the transport processes are accounted for by a MOM-like structure. They indicate that the sinking term originates a west-east gradient on biological parameters, while large gyres determine the prevailing trophic regime in the open ocean and upwellings/downwellings are most effective along the coastal areas.

THE IMPACT OF MESOSCALE EDDIES ON PRIMARY PRODUCTION IN THE NORTH ATLANTIC OCEAN: A MODELLING APPROACH

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Physical influences on biological primary production in the North Atlantic ocean are examined by coupling a four-component ecosystem model of nitrogen cycling to an eddy-resolving seasonal general circulation model. A series of sensitivity experiments shows the crucial role of an accurate formulation of upper ocean turbulence and of advection numerics. Subgridscale diapycnal diffusion strongly controls biological production in the subtropical gyre, while an accurate description of subgridscale viscosity is important in the equatorial region.
Assimilation of altimeter data from the combined TOPEX/Poseidon and ERS-1 missions into this basin-wide high-resolution model is performed to yield a more realistic representation of oceanic eddy activity. Results indicate that mesoscale activity accounts for more than one third of the new primary production in large regions of the subtropical and mid-latitude North Atlantic. Variational assimilation of ocean colour data in this coupled model is then conducted to constrain the modelled biological processes, and in particular to improve our estimation of poorly known biological parameters at a basin scale.

A MODEL STUDY OF THE EFFECT OF VERTICAL MIXING ON THE MARINE ECOSYSTEM

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A coupled 3-dimensional physical-biogeochemical ocean model is used to quantify the effect of vertical mixing on the marine ecosystem in the Atlantic Ocean, the Nordic Seas, and the Arctic Ocean. The physical model used in this study is the Miami Isopycnic Coordinate Ocean Model MICOM, with a dynamic-thermodynamic ice model, whereas differet nitrogen-based ecosystem formulations are used. Three mixing processes are examined: Mixed layer entrainment/detrainment, convective mixing, and diapycnal mixing. For the latter process, different parameterizations are tested, including vertical stability and isopycnic velocity shear dependent formulations. The presentation will focus on the effect these mixing processes have on new, regenerated and export productions in the open ocean, together with the air-sea exchange of CO_2.

COUPLED HYDRODYNAMIC ECOSYSTEM MODEL OF THE BLACK SEA AT BASIN SCALE. FIRST RESULTS OF A HIGH RESOLUTION 3D INTERDISCIPLINARY MODEL

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A hydrodynamical model of the general circulation in the Black sea has been build up, using the GHER (GeoHydrodynamics and Environment Research) three-dimensional, non linear, baroclinic, turbulent closure model. A model with 5 km horizontal resolution and 25 vertical levels is used to compute the typical seasonal cycle by forcing the model with climatological monthly mean fields of temperature, salinity and wind stress at the air-sea interface. Furthermore, the river discharges of the Danube, the Dnestr and the Dnepr are taken into account. This high resolution model resolves the baroclinic instabilities generated by the interactions of the boundary current with the coastline geometry or with the continental shelf/slope topography.
A simple ecosystem model defined by a nitrogen cycle is coupled with the hydrodynamical model. The state variables of this model are defined as those which are necessary and sufficient to assess the effects of the physical processes, and in particular of the boundary current instability, on the space time distribution of the primary and secondary productions.
The results of this 3D ecohydrodynamic model are compared with CZCS data of surface chlorophyll fields collected during the period from 1978 to 1986.

THE EFFECT OF HYDRODYNAMICS ON THE PHYTOPLANKTON PRIMARY PRODUCTION AND SPECIES COMPOSITION AT THE ENTRANCE TO THE GULF OF FINLAND (BALTIC SEA) IN JULY 1996.

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A two-week multidisciplinary experiment at the entrance to the Gulf of Finland with the aim to study the development of the late summer phytoplankton bloom and the controlling hydrodynamic mechanisms was carried out in July 1996. During the study period a clearly defined physical phenomenon - an anticyclonic eddy - was observed. The formation of the anticyclonic eddy was clearly reflected in the horizontal patterns of patchiness of phytoplankton. Diazotrophic cyanobacteria are favoured by low DIN and DIP concentrations because of overcompetition with other planktonic organisms. Proportion of cyanobacteria in the plankton community was the highest outside the observed eddy. The presumed vertical fluxes in the anticyclonic eddy appeared to be sufficient to control phytoplankton dynamics: the flagellates are favoured in case of continuous vertical transport of nutrients and, therefore, the flagellates abundance was higher in the centre and periphery of the eddy. Wind-induced vertical mixing was instrumental in bringing nutrient pulses to the upper mixed layer outside of the eddy and due to these pulses, temporal increases of phytoplankton (especially cyanobacterial) production was confirmed. A good correlation between preceding day wind speed and the phytoplankton primary production outside of the observed eddy was found.

MODELLING ANNUAL PLANKTON DYNAMIC IN THE IONIAN SEA (EASTERN MEDITERRANEAN)

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The annual cycle of the plankton dynamics in oligotrophic Mediterranean pelagic ecosystem, referring to the Ionian sea, is studied by a one-dimensional vertically resolved physical-biochemical upper ocean model, coupled with the Mellor-Yamada level 2.5 turbulence closure scheme. The biochemical model involves interaction between the inorganic nitrogen (ammonium and nitrates), single phytoplankton and zooplankton groups and detritus. As first step, under climatological forcing functions (wind-stress, heat and salt fluxes, photosynthetic active radiance), the model simulates main observed seasonal and vertical characteristic features as cold winter convection and yearly evolution of the upper layer stratification, the annual cycle of phytoplankton production with the weak spring bloom and the subsurface phytoplankton maximum layer stable in the summer - early autumn period.

PROJECTED DISPLACEMENT STATISTICS IN THE OCEAN

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Results from numerical models of unforced barotropic geostrophic turbulence over topography suggest that horizontal mixing is preferentially oriented along contours of the mean PV, here $f/H(x,y)$. This is most obvious if one considers displacement statistics in a coordinate system defined by the isolines of f/H. Here, I discuss what happens when one calculates such displacements for actual oceanic floats, and, in addition, regional and vertical variations of the corresponding statistics. The results indicate that oceanic mixing is also anisotropic with respect to f/H, implying in turn that topography affects the spread of tracer in large regions of the ocean. Certain statistical aspects are suggestive of Eulerian flows observed previously in turbulence models. Furthermore, the results lead naturally to simple parameterizations of horizontal mixing in the deep ocean.

PATHWAYS OF NUTRIENT SUPPLY TO THE OLIGOTROPHIC SUBTROPICAL GYRE: A MODEL STUDY

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Episodic nutrient pulses by eddy-induced upwelling have been suggested to explain why geochemical estimates of nitrate supply to the euphotic zone are an order of magnitude higher than biological and physical ones. The present study investigates the nutrient fluxes into the light-lit surface layer of the oligotrophic subtropical gyre with the aid of an eddy-resolving coupled biological-physical model of the North Atlantic. The level of eddy activity in the model is varied by assimilating altimeter data and by changing the parametrization of horizontal friction. The role of eddies in fueling biological production is compared with that of mean advection and different representations of subgrid-scale diapycnal mixing. It is found that eddies contribute about one third of the nutrient input into the subtropical Atlantic, but that they can not explain the large observational discrepancies. However, even within the subtropical gyre we find substantial regional differences in net nitrate supply, large enough to consistently explain the different observations. The model results are discussed with special emphasis on North Atlantic time series and process study sites.

THE INFLUENCE OF PHYTOPLANKTON ON THE MIXED LAYER AND SURFACE HEAT FLUXES

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The amount of light that is absorbed in the ocean is highly dependent on the amount of phytoplankton present. In an ocean mixed-layer model the thickness of the mixed-layer is sensitive to the amount of light that penetrates into the ocean. Thus accurate modelling of the light absorption must be included in ocean mixed-layer models. As a result, the mixed-layer thickness and surface heat flux dependency on the phytoplankton concentration can be evaluated.

The calculations carried out here to model the surface heat flux and the parameters that describe the mixed-layer, are based on Niiler's 1-D model, with modifications to take into account the concentration of phytoplankton.The absorption of incoming solar radiation is modelled accurately taking into account the exact absorption properties of chlorophyll as well as a dynamically varying concentration. The mixed-layer and the surface heat flux are evaluated using a set of realistic boundary conditions with varying windstress and incoming solar radiation.

MODELLING THE PHYTOPLANKTON SUCCESSION IN THE BARENTS SEA.

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There is some evidence that a succession towards a dominance of either of two prevailing algal species (diatoms and *Phaeocystis pouchetii*) can occur during the spring phytoplankton bloom in the Barents Sea. To clarify physical conditions at which the succession happens, a five compartment (diatoms, *P.pouchetii*, zooplankton, detritus and dissolved inorganic nitrogen) ecosystem model of the upper mixed layer (UML) is used. Two stages (solitary cells and colonies) of *P.pouchetii* development are considered, each stage of *P.pouchetii* as well as diatoms being characterized by different growth rate parameters. The model ecosystem is forced by the annual cycles of UML depth and sea surface solar radiation. Effects of the presence of snow-ice cover and related changes in the UML depth and solar radiation are studied. With a snow-ice cover, a heavy spring bloom of *P.pouchetii* in May is developed, although diatoms dominate before and after the bloom. With no snow-ice cover, diatoms dominate during the whole vegetation period. The dramatic change in phytoplankton community behaviour is connected with a decline in the growth rate of *P.pouchetii* after the transition from the cell to colony stage: a decrease in solar radiation due to the light absorption in the snow-ice cover does not allow them to reach high concentrations before the transition.

EDDY MIXING AND BIOLOGICAL PRODUCTION

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Ecological models of the upper ocean are often fitted to data by running a one dimensional version of the model and tuning adjustable parameters. However observations show that the physical, biological and chemical fields are very variable in the horizontal. The variability at the O(10km) scale is caused by the action of mesoscale eddies. Eddies mix water masses and produce vertical movement, both of which affect biological production. The affects of eddies on production need to be quantified in order that more robust ecological models can be formulated.

The effect of eddy action on production will be discussed. In particular results will be presented from a modelling study of eddy action on production. An ecological model is embedded into a physical model of an unstable oceanic front. Production is increased by the ensuing eddying motion. There is also a downward flux of material increasing the effectiveness of the biological pump. It is found that new production can be directly related to the vertical movement of nutrients into the euphotic zone caused by eddy action. A parametrization scheme based on the eddy transport scheme of Gent and McWilliams is developed and tested. the results are very encouraging and suggest a way of including the effect of eddies on biological production in basin scale ocean models.

PARAMETER OPTIMIZATION OF A SIMPLE MARINE ECOSYSTEM MODEL USING THE ADJOINT METHOD

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The modeling of interactions within a marine ecosystem requires information on biological control parameters. In the present study we have attempted to determine a set of various control parameters of a zero–dimensional biological NPH model (dissolved inorganic nitrogen, phytoplankton and herbivores) such that it gives the best fit to observations. The adjoint method has been used which is well suited for testing the consistency of biological dynamics with the relevant observations. Identical twin experiments revealed informations about model sensitivities close to the reference parameter values. Certain parameter combinations were found to be linearly dependent e.g. assimilation efficiency and the mortality rate of herbivores (zooplankton). The maximum grazing rate and the prey capture rate were redundant parameters for low chlorophyll concentrations. Assimilation of observation from different time–series stations in the North Atlantic showed the dominal influence of the mixed–layer (ML) depth variation. A monthly mean ML–depth variability results in model parameters corresponding to a bottom–up control of the ecosystem, whereas the inclusion of synoptic ML–depth variability leads to top–down control.

NEW PRODUCTION IN THE EQUATORIAL PACIFIC: A COUPLED DYNAMICAL/ BIOGEOCHEMICAL MODELLING

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A simple 3D biogeochemical model was coupled to a dynamical model in order to simulate new production in the equatorial Pacific during 1992-1995. The biogeochemistry was modelled as a chlorophyll-modulated nitrate sink. The model was able to reproduce the contrasting regimes of the equatorial Pacific: the biologycally poor warm pool region and the upwelled richer waters further east. A sharp salinity front separates theses two regimes. The zonal displacements of the front are associated with ENSO wind driven surface current variations. The simulation shows that nitrate front separates the two regimes and this front moves in phase with the salinity front. The model also shows that nitrate front displacements are governed by oceanic circulation.
However, the nitrate concentrations are higher in subsurface waters than has been observed in the equatorial upwelling region. Recent results of EqPac-JGOFS strongly suggest that a significant part of the dissolved organic matter escapes remineralization and is exported. Our biogeochemical model is thus improved by adding an explicit dissolved organic nitrogen compartement.

MODELLING OF DEPOSITION/RESUSPENSION PROCESSES IN THE ENGLISH CHANNEL

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ABSTRACT
Deposition and resuspension of particulate matter offshore Roscoff (western English Channel), were studied by *in situ* measurements of sedimentation rate and physical modelling of deposition/resuspension processes. Bottom-moored and free-floating multiple sample programmable sediment traps were deployed to measure the total downward sediment flux. Particulate matter sedimentation showed short-term variations which were partly related to tidal flow speed. Particle size distributions measured over the entire deployments were quite similar at mid-depth and close to the bottom. It mainly reflected the abundance of small particles in the sedimented material. The transfer processes in the water column along with the deposition and resuspension of particulate matter were modelled. Sediment production and resuspension were evaluate from the fluxes measured in sediment traps. The results obtained are very sensitive to the physical parameter values (vertical diffusion and particle fall velocity).

A ONE-DIMENSIONAL MODEL STUDY OF THE BIOGEOCHEMICAL SEASONAL CYCLES IN THE PO PRODELTA AREA (NORTHERN ADRIATIC SEA).

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A one-dimensional physical-ecological coupled model (Princeton Ocean Model - European Regional Seas Ecosystem Model) has been succesfully implemented in a coastal area directly influenced by the Po River.
Mixing processes are mainly determined by the interaction between the atmospheric forcing and the river runoff. Comparisons with observations show that the primary production seasonal cycle is reproduced with large discrepancies during strongly mixed seasons (autumn-winter), and agreement during much stratified periods (spring-summer).
Sensitivity analysis has been carried out in order to investigate the role of light penetration in the water column, that is strongly limited by the suspended matter concentration characterizing the prodelta coastal area. Different suspended matter forcings have been implemented and model result intercomparisons are showed.
Evidence has also been found of a possible change in the trophic web structure during different water column condition, showing a shifting between the "classical" trophic web and the microbial loop.

NP3 Transport and mixing in geophysical flows

Convener: Legras, B.

05 Transport and mixing of chemical species in the atmosphere, including urban and regional problems in the troposphere and global-scale problems in the troposphere and stratosphere (co-sponsored by OA & ST)

Convener: Haynes, P.H.

ARIMA MODEL ESTIMATION FOR URBAN OZONE AT THE CANARY ISLANDS AND ITS RELATIONSHIP WITH OTHER POLLUTANTS

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Based on the Ozone hourly data and other different pollutants as SO2, SPM, Nitrogen Oxides and CO obtained at an urban station placed close to a power plant of Las Palmas de Gran Canaria (Canary Islands), an ARIMA model has been determined to describe its evolution. First, trend and spectral analyses using the Fast Fourier Transform (FFT) to detect the different periodicities have been carried out. Once the model has been identified, the different relationship between the Ozone and the other mentioned pollutants have been determined. In order to detect these relations, the Cross-Correlation Functions (CCF) between the different prewithened series have been used. This technique has allowed to determine the characteristic time dependence on each one, caused by the photochemical transformations between the pollutants, showing different lags between them.

RELATIONSHIP BETWEEN TROPHOSPHERIC OZONE AND METEOROLOGICAL PARAMETERS AT TALIARTE (GRAN CANARIA).

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As it has been pointed out in precedent studies, ozone diurnal variations at Taliarte (Canary Islands) are dominated by two different situations: trade winds and marine breeze. Besides, a well-determined relationship between the presence of trade winds and low values of ozone registered at Taliarte, has been found. Multivariate ARIMA model and Cross Correlation Functions (CCF) have been determined to identify the influence of some meteorological parameters in the measured amount of ozone during several situations without the presence of trade winds.

MULTIVARIATE MODEL ESTIMATION USING METEOROLOGICAL PARAMETERS FOR URBAN POLLUTANTS AT GRAN CANARIA (CANARY ISLANDS).

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ARIMA model have been determined for several hourly series of pollutants at Las Palmas de Gran Canaria. Dry temperature, relative humidity and pressure have been chosen as meteorological parameters for the input of the mentioned multivariate model. It has been determined that high values of dry air temperature increase the photochemical transformations between the different pollutants. Also, the dependence of the pollutant transformation and the trade winds have been identified. Finally, stable, high-pressure episodes have been related to the pollutant persistence at the urban atmosphere.

THERMAL INVERSION IMPACTS ON THE MIXING PROPERTIES OF THE LOW ATMOSPHERE WITHIN A DEEP VALLEY

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Pollution problems within deep valley systems are associated to low wind conditions with significant stratification including a strong inversion layer, which reduces the exchanges towards larger scales.
Previous studies have shown that the structure as well as the characteristic scales (height, strength, and duration) of the thermal inversion within the valley strongly depend on the season. These results can be interpreted for urban pollution planning since the dynamics scales are in the same order of the reactive chemical processes.
Our contribution deals with the large eddy simulations of a complete diurnal cycle of atmospheric flows within different schematic valleys. atmosphere.
The main objectives are to point out the influence of the valley aspect ratio and the influence of the shape (convex or concave V or U-shaped valley) on the characteristic scales of the thermal inversion. The impact on the mixing properties of the lowest layers of the atmosphere, linked to the time evolution of the stratification whitin the valley, is shown through the visualization of the iso-concentration of a passive scalar emitted in the centre of the valley during three different periods : at the end of the night (when the thermal inversion is the strongest and when its vertical extension is maximum), at noon (when the inversion is the weakest or completly destroyed), and at sunset.

A TRACER CLIMATE MODEL BASED ON THE LMDZ AGCM

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On the basis of the new LMDz atmospheric general circulation model a tracer climate model has been developped. The implicit scheme of the boundary layer and the convective and advective schemes of the GCM were altered to include passive tracer transportation. Furthermore the possibilities of dry and wet deposition as well as radioactive decay were implemented. The general features of this model have been validated simulating the atmospheric cycles of ^{222}Rn and ^{210}Pb, and lately through the simulation of mineral dust, a tracer of more climatic significance. A special feature of the applied GCM is the ability of applying a stretched grid. This means that the resolution can be increased to near mesoscale over specific areas of interest, with the model remaining global at reasonable computational cost.

TWO YEARS LIDAR AEROSOL MEASUREMENTS AT THESSALONIKI, GREECE

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Measurements of the vertical lower tropospheric profile of the aerosol backscattering coefficient have been performed at the city of Thessaloniki, since 1996 using a ground-based backscattering lidar system operating, simultaneously, at 355 nm and 532 nm. Measurements have been carried out throughout the year around local noon hours and during extensive time periods. The different aerosol loads and their vertical extension in the urban lower troposphere, between the "warm" and "cold" periods over Thessaloniki are discussed. Case studies of the diurnal evolution of the aerosol layer over the city of Thessaloniki have been examined under different meteorological conditions prevailing in the area. From the analysis of these studies the origin of the aerosol layer is indicated and the evolution of the boundary layer over the site is described. Two cases are also presented, when dust lifted from Sahara desert was transported over the measuring site. The height of this layer was determined between 3-4 km and the optical depth at 532 nm of the Sahara dust layer was found to be of the order of 0.1.

ADAPTIVE PARCEL ADVECTION

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We present a method for performing trajectory analyses using an adaptive irregular mesh to allow refinement of the resolution of the flow. We keep track of nearest neighbours using Delaunay triangulation. Where parcel densities drop below a critical value, extra parcels can be added. Similarly parcels can be removed where the density exceeds a threshold. The critical value can be set using geographical information, (e.g. more parcels in the Northern hemisphere), dynamical quantities (e.g. shear in the flow field), tracer gradients, or other desired parameters. Arbitrary moving boundaries can be included to confine the parcels to a pre-defined region. Variable timesteps are incorporated to allow for the changes in resolution from place to place. The technique can be used in two or three dimensions. We compare two-dimensional results with contour advection calculations by concentrating the parcel density close to a fixed value of a tracer initialized using the potential vorticity on an isentropic surface. The potential for extension of the method to a full dynamical model will be discussed.

NP3

MODEL HIERARCHY FOR THE DETERMINATION OF METEOROLOGICAL AND CHEMICAL PROCESSES

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The global, regional and local scale model hierarchy ECHAM-REMO-GESIMA is being developed to improve the understanding of formation processes of photooxidants together with the changing oxidizing capacity of the atmosphere especially in the European/German area. The models are coupled every 6h (global-regional) up to 1h (regional-local) by one-way nesting, meteorology and chemistry is determined simultaneously (on-line).
A summer smog episode in 1994 was chosen for a first application of the mesoscale part of the model system (REMO-GESIMA). Preliminary results focussing on ozone prediction and scale dependence of several trace gas distributions are subject of interest. For the future it is planed to use the complete model hierarchy for analyzing climate and emission szenarios based on global simulations with the climate model ECHAM.

HIGH RESOLUTION FORECASTS OF POLAR STRATOSPHERIC OZONE USING THE CANADIAN GLOBAL ENVIRONMENTAL MULTISCALE MODEL

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Preliminary high resolution forecasts of polar stratospheric ozone are presented using the Global Environmental Model (GEM), an innovative model operationally used at the Canadian Meteorological Center. Here we use it in a regional configuration where the resolution is focused over either one of the polar regions, to study the effect of resolution on a simple stratospheric ozone chemistry. Both the sensitivity to the horizontal and vertical resolutions are examined by considering uniform 50 km and 25 km horizontal meshes over the area of interest, and by increasing the number of vertical levels in the stratosphere. The UKMO analyses are used to initialize the dynamical variables of the model while analyses based on total ozone data from the Global Ozone Monitoring Experiment (GOME) provide the initial conditions for chemistry. These univariate analyses of ozone were obtained with a 3D-variational assimilation (3D-var) developed out of the CMC operational 3D-var. The EOF associated to these analyses are also presented to assess the quality of the assimilation system.

ON THE MODELLING OF CLIMATOLOGICAL CHARACTERISTICS OF PHOTOCHEMICAL SMOG IN BOHEMIAN BASIN

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The transport of air pollution on the regional scale (Bohemian region) is presented. The results of Charles University puff model for the imission assessment are used to give information on the concentration fields of ozone, nitrogen oxides and other ozone precursors. Current version of the model covers up to 16 compounds and it is based on trajectory computation using climatological wind roses and puff interaction both by means of Gaussian diffusion mixing and chemical reactions of species mentioned above. The alternative approach in terms of episodes studies can be solved as well, i.e. appropriate meteorological data can be used to estimate immision characteristics both for episodes analysis and, in case of connection to meteorological model forecast, the prediction of future air quality conditions.

RELATIONSHIP BETWEEN METEOROLOGICAL PARAMETERS AND SYNOPTIC CONDITIONS WITH EPISODIC PERIODS AT SANTA CRUZ DE TENERIFE (CANARY ISLANDS)

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Through the use of the data provided by an urban pollutant measurement station placed close to a refinery plant at Santa Cruz de Tenerife (Spain), several high pollutant concentration episodes have been analysed. The data provided by a captive balloon have been plotted on a Skew T û Log p thermodynamic diagram to describe the typical conditions of the lower layers of the atmosphere for each day analysed. Once these conditions have been determined, the synoptic patterns related to all these situations have been identified. A S-SE wind flow related to a high-pressure area placed at the Saharian area gives a subsidence inversion at the lower layers of the atmosphere. Both features depict the typical conditions related to these episodic situations.

OBSERVATION OF ATMOSPHERIC BOUNDARY LAYER CHARACTERISTICS OVER AN URBAN SITE

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The diurnal evolution of urban boundary layer over the central area of Rome was observed by the simultaneous and co-located operation of a Doppler sodar and a microwave ratiometer. The Doppler sodar was configured to provide a wind profile up to about 900 m for every 6 s with a height resolution of 27 m, and a time-height picture of the thermal structure of the urban boundary layer. The radiometer provided a temperature profile up to 600 m for every 120 s with a height resolution of 50 m. The experiment was conducted for a period of 30 days in the years 1996 and 1997. Although the daytime urban boundary layer was mostly characterized by the development of thermal plume structures up to a height of about 700 m, the nocturnal urban boundary layer showed a variety of features including the occurrence of Kelvin-Helmholtz waves, solitary-type waves, multiple-layers, etc. The occurrence of surface-based inversions was found to be rare. The height of the urban boundary layer during night-time was around 300 m and was near-adiabatic to isothermal in character. Some typical case studies are discussed.

SENSITIVITY OF OZONE PHOTOCHEMISTRY IN A POLLUTED AREA

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We study the sensitivity of ozone concentrations in an urban area to several parameters using a chemistry-transport box model. First, the influence of meteorological factors such as mean wind intensity, cloudiness and mixed-layer height is examined. Then, various upstream emission rates of nitrogen oxides and hydrocarbons are considered. Finally, we take into account different vertical mixing processes - namely local vs non-local processes - within the urban boundary-layer using the transilient theory approach. The effects of these parameters are studied with respect to the mean chemical reactivity as well as the existence of low and high NOx photochemical states in the urban boundary-layer.

A STUDY OF LAGRANGIAN TRANSPORT IN A WIND DRIVEN, 3-LAYER, EDDY-RESOLVING GENERAL CIRCULATION MODEL USING DYNAMICAL SYSTEMS THEORY

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We study the flow obtained from a 3-layer, eddy-resolving general circulation model subject to an applied wind stress curl. For this model we will consider transport between the northern and southern "gyres" separated by a jet. We will focus on the importance of invariant manifolds in forming geometric structures that govern transport. By "govern", we mean they can be used to compute Lagrangian transport quantities, both deterministic and statistical. We will consider periodic, quasiperiodic, and chaotic velocity fields, and thus assess the effectiveness of dynamical systems techniques in flows with progressively more spatio-temporal complexity. The significance of invariant manifolds as signatures of specific "events", such as rings pinching off from a meansering jet, will also be discussed. The relation of these concepts to potential vorticity dynamics be considered.
This research is supported by the Office of Naval Research through contract number NOOO14-97-1-0071.

DISPERSION THROUGH LARGE GROUPS OF OBSTACLES

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Although there have been many studies of the flow around isolated buildings, much less is known about the effect of groups of obstacles on the flow and dispersion in the atmospheric boundary layer. For many practical calculations it is not feasible to represent all the obstacles individually, and in such cases it is necessary to model the collective effects of the obstacles. The aim of this study is to investigate the influence of the topology of the flow – the convergence and divergence of the streamlines of the mean flow – on the dispersion of a passive scalar. We consider here a two-dimensional flow containing solid squares organized into different regular configurations (aligned, staggered). The mean flow through the group of obstacles is computed using a potential flow model, based on the 'Vortex Panel' method. The turbulent dispersion of a passive scalar from a point source is computed by coupling the mean flow model with a stochastic 'Random Flight' model. We investigate the influence of obstacle size by varying H whilst keeping the porosity constant. In this case the obstacle size determines the spacing between the obstacles. It should also have an influence on the length scale of turbulence, since it can be expected that the obstacles will block motions at scales larger than themselves. The results provide parametric scalings for the effects of configuration and obstacle size on the behaviour of a plume of pollutant

A comparison of flight measurements from Summer '97 with TOMCAT

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In the summer 1997 a large number of aircarft flights took place over the North Atlantic ocean looking at the transport of pollutants from continental regions. The flights were for a number of campaigns including the NERC ACSOE. Measurements of important tropospheric species were made, including ozone, NOx, and carbon monoxide. Our Cambridge off-line 3-D tropospheric model, TOMCAT, was compared directly with the measurements made along flight tracks. TOMCAT has a detailed description of tropospheric chemistry. ECMWF meteorological analyses are used to force the model transport, for the period June to October 1997.
The flights were made in airmasses of different origin exhibiting different chemical signatures.

STRATOSPHERIC OZONE, NITROGEN DIOXIDE and TEMPERATURE MEASUREMENTS at (44N, 11E) DURING 1996-'97

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The future trend of stratospheric ozone at mid and low latitudes is subject of increasing scientific interest. It is a subsequent of the need to clarify better the ozone loses caused by the local processes from the loses invoked by horizontal or vertical transport or from other factors contributing to ozone depletion.
The present paper deals with ground-base measurements of stratospheric ozone, nitrogen dioxide and temperature profile carried out during two years period. The stratospheric ozone and temperature data are collected by means of ECC and temperature sensors mounted on sondes, launched regularly at St.P.Capofiume(44.65N, 11.5N) WMO #297station. The lidar measurements at Brasimone (44.18N, 10.7E) supply upper stratosphere and low mesosphere temperature data. NO_2 data are provided from DOAS measurements in 407+460nm spectral interval, carried out in Bologna (44.5N, 11.28E) and Mt.Cimone (44.2N, 10.5E)
The obtained experimental data are analysed and compared to satellite data and models predictions to look for transport and dynamic influence upon seasonal ozone variations.

ATMOSPHERIC OZONE LINE OBSERVATIONS IN A FREQUENCY RANGE OF 90-110 GHZ.

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The results of ozone line observations conducted at Nizhny Novgorod (Russia) during 1996-97 are presented. 3^{mm} spectral line radiometer has been employed with the frequency resolution of 2 MHz and system noise temperature of 1200 K. 4 ozone lines were observed with the resonant frequencies of 96228, 101736, 103878 and 110836 GHz as the most intensive lines in operating waveband. Two first lines are observed systematically since February, 1996, till present time. The main objective of this project is to obtain the reciprocal intensities of ozone lines belonging to different transitions. Such measurements are supposed to be informative on the energy levels distribution of ozone molecules. In turn, this is important for an adequate estimation of ozone integral content and density profile. Average measured value of 101736/96228 line intensities ratio equals to 2.11±0.38 in comparison with its theoretical value of 1.8 (under LTR conditions). Two other ratios are 0.55±0.15 (103878 line) and 2.16±0.8 (110836 line) as regards to the same 96228 GHz line. Corresponding theoretical ratios are 0.6 and 2.5. Under observations, a significant deviation in ratios from their mean values were revealed presumably due to changes in physical conditions of atmosphere.

ENSURING ECOLOGICAL SAFETY OF MOTOR TRANSPORT IN URBAN OF CONDITIONS.

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Analysis of ecosystems condition is conducting: "Human being + car + environment" of a city as operating environment of motor transport. Adaptation of operation and system parameters of a fuel supply system of engines of modern cars to the concrete condition of their operating are determined. Structure analysis of mathematical model was made. Foundation of schemes and parameters of pollution indicator of air filters of engine fuel supply system are given. Specified technical actions on raising of ecological safety of modern cars in conditions of city.

NP3

STRATOSPHERIC OZONE, NITROGEN DIOXIDE and TEMPERATURE MEASUREMENTS at (44N, 11E) DURING 1996-'97

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The obtained experimental data are analysed and compared to satellite data and models predictions to look for transport and dynamic influence upon seasonal ozone variations.

On the importance of horizontal resolution and mixing in the modeling of the impact of aircraft emissions

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Mixing in the atmosphere is critical for the chemical evolution of the air contained in a plume. In particular, if the mixing is much faster than the timescale associated with chemistry, then it can be expected that the chemical state of the atmosphere will rapidly be equivalent whether the emissions were initially confined to a plume or instantaneously diluted. This dilution is implicitly related to the resolution at which the emissions are distributed in a model. Using a two dimensional chemistry/transport model, the problem of emissions mixing is studied in application to aircraft emissions. The modeled impact of aircraft emissions is shown to be dependent on the horizontal resolution at which the emissions are input into a model. Over the scales and for the conditions studied, the artificial dilution of the emissions due to their inadequate representation in coarse resolution models enables a more efficient reaction from NO_x (= NO + NO_2) to HNO_x (= HNO_2 + HNO_3 + HNO_4).

TELLURIC LINE OF N_2O AS AN INDICATOR OF ATMOSPHERIC TRANSPORT

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Nitrous oxide rotational lines were calculated using modern *in situ* data on its vertical distribution in Earth's atmosphere. These lines width and intensity subject to variations due to changes in N_2O density profile. In equatorial atmosphere, the mean value of line width equals to ~0.6 GHz insreasing up to ~0.9 GHz at moderate latitudes. This is a sequence of stratosphere being more rich of nitrous oxide in equatorial zone than at moderate latitudes owing to correspondent difference in convection. It implyes the N_2O line possible variations even at moderate latitudes, if the atmospheric transport has changed. This conclusion is supported with the results of N_2O line observations conducted at Nizhny Novgorod (Russia) during March-May of 1997. A 3-mm spectral radiometer was employed with the system temperature as high as 1200 K. The spectra were taken with 2 MHz resolution using the 30-channel filter spectrometer. Nitrous oxide rotational line (J=3→4 transition corresponding to the resonant frequency of ~100,5 GHz) shows variations in its optical depth decrement measured at the frequency shift of 25 MHz from the resonance. During the observations, the decrement has increased by 3-5 times thus implying the significant redistribution of N_2O in a height region of 20÷55 km.

THE SWISS EPFL LIDAR IN THE EU WINTEX PILOT STUDY.

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The contribution of particulate matters as Mie scatters on LiDAR measurements is know to be an efficient tracer for the planetary boundary layer (PBL) height and development in polluted regions. A similar approach was proposed for the WINTEX study in March 97 at Marsta, Sweden, but for very clean boreal air conditions. In case of clouds covering at the height of the inversion layer, this aerosol LiDAR, operated at 532nm (total backscattered) and 355nm (polarized), could follow and retrieve this height, while in clear sky conditions, this PBL height tends to be more difficult to detect. Different meteo conditions will be presented, in particular the increase of the mixing height in the early afternoon due to the solar warming up of the ground.

AEROSOL STUDIES OVER NORTH ATLANTIC

V. N. Lukashin (1), A.B. Isaeva (1), V.V.Serova (1), V.YU. Gordeev (1) and R. Stein (2)
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Concentration and composition of aerosols in the North Atlantic were studied. There are data on particle sizes, contents of C, N, P, Si and Al, results of REM-EDAX analysis. It is showed that lithogenic component contents decrease and organic increase when going off the continents. Comparing of mineral component fluxes from atmosphere to the sea surface with rate of sediment accumulations ("absolute masses") on the floor evidences about important of the aerosols for the ocean sedimentation.

LIGNIN AND PHENOLS IN AEROSOLS OVER CENTRAL ATLANTIC

V. I. Peresypkin and V. N. Lukashin
P. P. Shirshov Institute of Oceanology, Moscow.

It was researched distribution and composition of the lignin and phenols over the Central Atlantic on cross- section (15 N). Content of the identified phenols varies from 35.6 to 588 mkg/g in air-dried matter (2.06-8.09 percents from organic carbon). Calculated content of lignin in the samples is from 83.5 to 3645 mkg/g (16.7-51.9 percents from organic carbon). Prevalence of the p-hydroxyl structures above the vanillin and syring ones is observed in all samples excluding the sample collected near Cape Verde Islands. That relation indicates on transportation by the air masses of large quantity of the plant sporopollenin in which p-hydroxyl structures are dominated. Vanillyl and syringyl structures are in the particles of the higher plant. All noticed components fall on the sea surface and through water column to the bottom sediments, where are preserved for a long time.

COUPLING BETWEEN CHEMISTRY AND MIXING IN A SIMPLE REACTION DIFFUSION SYSTEM

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For many years the environmental concentration of OH has been estimated from the differential change in concentrations of hydrocarbons of differing activity. The normal approach is based on the simplifying assumption that chemical and transport processes are seperated. However consideration of the continuity equation for a reactive species with source and sink terms leads to the conclusion that this simplifying assumption is not generally valid. In this paper new analytic solutions to some steady state diffusion equations will be presented and it will be shown that the seperability assumption of the observational OH studies is valid for all practical purposes. The concept of a coupling constant that is a simple function of the equation constants will be introduced. Finally it will be shown that when values of the coupling constant more appropriate to large scale numerical models are employed the likelyhood of interactions between chemical and mixing processes is much more likely.

ALIPHATIC HYDROCARBONS IN AEROSOLS OVER CENTRAL ATLANTIC

V. I. Peresypkin and V. N. Lukashin
P. P. Shirshov Institute of Oceanology, Moscow.

It was studied distribution and composition of the alkane-naphtene fraction of the organic matter in aerosol samples collected on cross-section from the Mid-Atlantic Ridge (15 N) to Dakar. Contents of the organic carbon vary from 0.84 to 4.45 percents (dry matter), the hydrocarbons - from 91.0 to 1079 mkg/g, the n-alkanes - from 11.69 to 32.02 percents (from hydrocarbon content). Maximums of C25 , C27, C29, C31, C35 and C39 indicating on presence of higher-plant wax dominate in distribution of the biomarkers-n-alkanes. Ratios Pr/Ph vary from 0.87 to 4.17, C10-C 22/C 22-C 40 - from 0.04 to 0.26, CPI - from 2.32 to 6.29. Thus, the continents are source of the terrigenous lipids transported into central areas of North Atlantic by trade winds.

GREENHOUSE GASES IN THE LMD-Z GENERAL CIRCULATION MODEL

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O. Boucher (Laboratoire d'Optique Atmosphérique, UFR de Physique, Bat P5, Université de Lille I, 59655 Villeneuve d'Ascq Cedex, France)
M. Pham, D. Hauglustaine, C. Granier (Service d'Aéronomie, B102, Univ. Paris 6, 4, place Jussieu, 75252 Paris cedex 05, France)

In order to investigate the climate effect of greenhouse gases in an interactive way, greenhouse gases have been introduced in the new version of the general circulation model LMD-Z developed by the Laboratoire de Météorologie Dynamique (LMD).
This preliminary study presents the distributions of CH4, N2O, CFC11, and CFC12 as simulated by LMD-Z.
Surface emissions map for these gases are provided by the up-dated emissions inventories of GEIA and EDGAR.
In this version, chemical and photochemical sinks of the concerned species are calculated off-line with the IMAGES (Intermediate Model for the Annual and Global Evolution of Species) OH distributions and the photodissociation tables obtained with the model MOZART (Model of OZone And Related chemical Tracers). Wet and dry deposition are also taken into account.

SIMULATION OF TRACE-GAS DISTRIBUTIONS WITH THE UIUC 3-D ATMOSPHERIC CHEMICAL-TRANSPORT MODEL AND COMPARISON OF SOURCE GAS DISTRIBUTIONS WITH OBSERVATIONS

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The study of the interaction between climate and chemistry requires the development of fast and accurate submodels that describe photochemical processes and gas transport in the atmosphere. Due to computer time constraints, a number of parameterizations have to be used in such submodels. Accordingly, a detailed validation of the chemical and transport routines should be carried out. One of the best ways of validation is to compare the simulated gas species distributions with satellite climatological datasets. Here we present the 3-D UIUC Atmospheric Chemical Transport model. The model consists of three submodels: (1) A hybrid transport routine, (2) a photochemical routine, and (3) circulation fields generated by the our 3-D 24-layer AGCM. The results of an 8-year steady-state model run are analyzed and the distributions of the long-lived species are compared with appropriate HALOE and CLAES datasets. The simulated monthly zonal-mean mixing ratios of long-lived species are in reasonable agreement with observational data. The correlation between the simulated and observed distributions of long-lived species and the tracer-to tracer correlation show the very good overall performance of the model.

Investigation of high pollution episodes in background regions

Sergey V. Chereshnuk (Moscow State Univercity, Lenin hills, Moscow,
Russia)

The idea of this study was to investigate high pollution episodes in background regions for most anthropogenic substances Pb, Hg, Cd and benz(a)piren. The study was performed for Borovoe (North Kazahstan) and Lesnoe (Russia) stations.
In the work statistics was calculated, and back trajectory was selected which meets high concentrations.
As a result a relationship between concentrations at observation site and spatial source distribution was found, and environmental conditions in two background regions was compared.

THE ROLE OF REGIONAL TRANSPORT IN URBAN PHOTOCHEMISTRY

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The influence of long-distance transport of ozone and its precursors from remote areas on the photochemical smog formation is examined in different respects. First we demonstrate that it is a dominant effect in the Paris area, which allows one to doubt about the impacts of local traffic restrictions during these episodes. Second we examine in a more general manner the modifications of the local chemical regimes induced by this long-distance transport and show that nox-sensitive photochemical production can happen in certain circumstances even over a large city. We also examine the predictability of the ozone concentrations according to the previous considerations.

MODELLING THE TURBULENT DISPERSION OF POLLUTANTS IN CITY STREETS

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We need to be able to compute the concentration of atmospheric pollutants in city streets so that we can estimate the impact of such pollution on the inhabitants, so that we can interpret the point measurements provided by static pollution monitors and so that we can estimate the flux of pollutants emitted by the urban environment into the external atmospheric boundary layer. In many practical cases it is possible to idealise a large street as a long, quasi-2D cavity bounded by relatively large buildings. The flow within the cavity is then driven principally by the wind blowing over the top of the cavity, and consists of one or more eddies (depending on the aspect ratio of the cavity) trapped within the cavity. This type of representation is known as a 'street canyon' model. We have developed a new street canyon model which is intermediate between large CFD codes and empirical expressions for the concentration of pollutants. The basic principle of the model is that the flow inside the cavity is computed using a combination of potential flow and fixed, point vortices. The transport and dispersion of material within the cavity is modelled by the advection-diffusion equation, solved by using a conformal transformation to map the physical domain onto the $\phi - \psi$ plane, where we can use standard solutions of the equation. This model gives very good agreement with experimental results for the concentration field in the cavity.

NP3 Transport and mixing in geophysical flows

Convener: Legras, B.

06 Mixing in the interior of the Earth (recycling of subducted slabs) (joint with SE)

Convener: Ricard, Y.

MANTLE MIXING: INFLUENCE OF 3-DIMENSIONALITY AND VISCOSITY STRATIFICATION

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Mixing properties of the mantle remain puzzling. One does not precisely understand how the mantle convection can destroy the chemical and isotopical heterogeneities of the lithosphere, and in particular, what kind of mixing times are related to this re-homogenization. While geodynamicists favor efficient mixing by deep slab penetration, various geochemists advocate for the existence of unmixed reservoirs. We compute various 3-D cavity flows with imposed surface conditions mimicking tectonic plates and advect passive tracers in order to quantify their mixing abilities. The 3-dimensionality of our model allows us to choose plate geometries with both converging/diverging margins which induce vertical transport and strike slip margins which only mixes the mantle on horizontal planes. Internal masses simulating subducting slabs can also be imposed. We study the effects for the mixing rates on the one hand, of the toroidal over poloidal energy ratio (e.i. the relative importance of surface strike slip to diverging motions), and on the other hand, of a viscosity increase in the lower part of the system (which mimics an 'upper' and a 'lower' mantle). We will see that the time-dependence of the flow is not necessary to obtain chaotic areas with efficient mixing in 3-D models. Simple flows will also illustrate the possibility to maintain some unmixed reservoirs even without viscosity stratification. We will discuss different ways of quantifying the mixing efficiency, and present scale-dependent mixing times for various models of the Earth's interior.

QUANTIFYING MIXING IN NUMERICAL MODELS OF MANTLE CONVECTION

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Recent high-resolution seismic images of subduction zones appear to indicate that slabs extend into the lower mantle, possibly to the core-mantle boundary. This is consistent with a circulation pattern that encompasses the entire depth of the mantle and suggests efficient recycling of subducted slab. Models of the geochemical evolution of the mantle, on the other hand, seem to require several distinct "reservoirs" of differing mean age and trace element composition, suggesting that recycled slab is not efficiently mixed within the mantle. An important question in mantle dynamics is whether large regions can develop different residence times (maintaining distinct reservoirs), or whether a different explanation of the geochemical data is called for. We developed quantitative measures for assessing mixing in numerical models of mantle convection. Tracer particles, introduced to simulate subduction and formation of oceanic crust, form fractal distributions with dimensions that depend on the model parameters. The distribution of mean ages provides a measure of the geochemical evolution of different regions. We investigate the role of viscosity stratification across the transition zone and in the D″ region on formation and destruction of heterogeneities. Viscosity stratification slows the transport of slabs across the transition zone, but the slowed transport does not stratify the mantle geochemically. Old slab material survives longer in a viscously stratified mantle, but the recycled slab is not concentrated into discrete reservoirs.

CONVECTIVE MIXING CONTROLLED BY PHASE TRANSITIONS AND THE SIZE DISTRIBUTION OF CHEMICAL HETEROGENEITIES IN THE EARTH'S MANTLE

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It is now generally recognized that the convective circulation in the Earth's mantle is neither completely layered by the 670 km discontinuity nor does it cross this horizon completely unhindered. Many non-linear simulations of thermal convection in this region of the Earth have demonstrated the critical role played by the endothermic phase transition that defines this horizon in controlling the mass exchange between the lower mantle and the upper mantle and transition zone. Geochemical measurements of mid-ocean ridge and ocean island basalts show different degrees of elemental depletion indicating the existence of at least two distinct chemical reservoirs in the Earth's mantle which are often associated with the lower mantle and upper mantle and transition zone. The scale of chemical heterogeneities within these reservoirs, which are likely controlled by the scale of the mass flux events transiting the 670 km horizon, remain poorly constrained. We will describe a suite of high resolution numerical simulations of thermal convection in the Earth's mantle which include the effects of the endothermic phase transition in which we characterize the size distribution of trans-670 km mass flux events. We will demonstrate that for certain parameter regimes, the size distributions display scale invariance.

Is there a missing link between geochemistry and geophysics of the convective mantle ?

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While in Geophysics, information about the convecting Earth mantle is carried by signals in which spatial characteristics of the medium through which these have propagated are particularly important, in Geochemistry, measurements rely on rock samples, the matter of which has essentially lost most of the memory of their travel throughout the mantle until the outcrops where they have been picked up. Up to now, one fruitful approach developped in Geochemistry is by considering reservoirs and budget complementarities, approach for which isotope tracers are of the most pertinent geochemical tools. However, this "globalistic" approach gives little information about spatial disposition of these reservoirs. A refinement of this is to consider the heterogeneity of the reservoirs through the isotopic ratio distributions, which is a purely statistical point of view rather than a spatial one. Evolution models of convective stirring can thus be tested for being able to sustain the kind of steady-state heterogeneity that these isotopic distributions quantify. Thus, in order to generalize these direct observations provided by geochemists from the analyzed rock sample collection to their whole source reservoir, one must first be fully convinced that this sampling is either representative of its mantle source reservoir, and/or that biases can be evaluated. If reweighted statistics are an attempt to bring an affordable solution for the second "drawback", the first assumption can only be approached through convection modelling in which a ridge sampling scheme is taken into account.

MIXING IN VIGOROUS, TIME-DEPENDENT 3D CONVECTION

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An understanding of the mechanism of mixing in highly viscous convecting fluids is of crucial importance in explaining the observed geochemically heterogeneous nature of the Earth's mantle. Using constant viscosity numerical experiments, we describe the mixing mechanism of time-dependent Rayleigh-Bénard convection with an infinite Prandtl numer in a three-dimensional rectangular container. Mixing is observed by following the positions of passive tracers advected by the flow. The major mixing mechanisms may be described in terms of the within-cell mixing and the cross-cell mixing. The flow structure in which tracers move on toroidal surfaces, that was previously observed in steady-state 3D convection systems is perturbed by boundary layer instabilities in the time-dependent experiments. This flow structure allows a very efficient exchange of mass between the boundary layers and the core of the convection cell even in the absence of time-dependence. We compare this results with calcluations carried out in two spatial dimensions. The inferred mixing rates are observed to be relatively insensitive to initial tracer location, but the timescale for mixing, t_m, decreases with increasing Rayleigh number. The timescale of mixing is an important constraint on the large scale structure of the Earth, because large-scale geochemical heterogeneities persist to the present day, implying that the mantle is not well mixed.

EFFECTS OF TOROIDAL FLOW AND RHEOLOGICAL HETEROGENEITIES ON MIXING IN THE MANTLE

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Large scale mixing of chemical heterogeneities in the Earth's mantle is accomplished by the stretching and folding motion associated with mantle convection; diffusional processes are only important on centimeter length scales. Chaotic flows will promote effective mixing; these can be produced by time dependent flows and also by the presence of toroidal components of flow (which are only present in 3 dimensions). Plate tectonics produces both in the mantle, and hence mixing should be effective, especially in the upper mantle where the effects of plate flow are largest. The lower mantle may be less well mixed owing to its higher viscosity and the relatively small toroidal flow. Studies of simple flow systems with poloidal and toroidal flow components demonstrate the chaotic nature of the flows and constrain the time constants for efficient stirring of the mantle. Considerations of time scales for the Earth indicate that the upper mantle should be well mixed. Geochemical observations indicate the presence of long-lived heterogeneities in the mantle. Simple flow calculations show that viscosity heterogeneities strongly influence mixing. Weak blobs are rapidly deformed and dispersed in a larger scale flow, while high viscosity blobs can resist deformation and dispersal for times that are geologically long. Such heterogeneities may account for geochemical reservoirs in the mantle.

Mixing Efficiency in the Upper Mantle

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We have investigated the relative mixing efficiency between Newtonian and non-Newtonian temperature-dependent rheologies operating in the upper-mantle. This method is based on assembling many passive tracers on line . The particles are dynamically redistributed at each time-step. They are then advected by the velocity field produced by thermal convection . Up to one million tracers per line and ten lines ten lines have been employed for following the the time-history of a source of heterogeneity. Based on the mass transfer history through the horizontal layers we can construct the statistical characteristics and follow the dynamics over a phase plane consisting of the depth and time . The mixing characteristics are different between the two rheologies. Non-Newtonian rheology retains long-living horizontal structures, while Newtonian rheology produces vertically stratified columns. Greater amount of deformation is produced by the Newtonian convection. Mixing is less efficient for non-Newtonian rheology as islands with unmixed material still persist. The length of the lines grow with time in a power-law fashion for Newtonian . The lines produced from both rheological flows display fractal behavior, which increases with time.

NP4 Nonlinear waves, coherent structures and natural hazards

01 Nonlinear waves, instabilities and wave-flow interactions

Convener: Shrira, V.I.
Co-Convener: Ostrovsky, L.A.

A NEW ANALYTICAL MODEL FOR OCEANIC INTERNAL SOLITON PACKETS

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We advance a new analytical model to describe packets of internal solitons in the ocean. Such nonlinear waves are often generated by tidal flows across bathymetric features that protrude into the pycnocline. The model builds on the "dnoidal" solution to the KDV equation The basic solution for the vertical displacement of an isopycnal surface is given in terms of the Jacobi elliptic function, $\mathrm{dn}(x, s)$ as

$$\eta(r,t) = 2\eta_0 \left\{ \mathrm{dn}_s^2 \left[\frac{1}{2} k_0 \left(r - V(s)t \right) \right] - (1 - s^2) \right\}$$

where s is a nonlinear parameter to be determined from other considerations. Field data, e.g., in-situ measurements or satellite images can be used to derive the variation of s within a packet. The resultant solution has many of the properties possessed by the observed solitons: amplitudes, wavelengths, and phase speeds that decrease from front to rear; an increase in the number of oscillations with space and time; and a long-term depression of the pycnocline in the wake of the packet. We increase the realism of the solution by modifying $\eta(r,t)$ to include tidal modulation, vertical variation, and attenuation. Comparisons are made with observations in the Mid-Atlantic Bight and the Strait of Gibraltar.

A MODEL OF QUASI-PERMANENT THREE-DIMENSIONAL GRAVITY-CAPILLARY WATER WAVE PATTERNS

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A weakly nonlinear model of three-dimensional quasi-stationary patterns of gravity-capillary waves is presented. The pattern consists of three short (capillary) and one long (gravity-capillary) components. For the Bond number $B = \sigma k_0^2/g > 1$ (σ — surface tension, g — gravity acceleration and k_0 — wavenumber of a short wave) both three- and four-wave resonances are important. Short harmonics form a resonant quartet; long wave and a pair of short harmonics constitute a resonant triad. The three-wave resonance conditions can be interpreted as synchronism of the short wave packet and long-wave component. Coupling of three- and four-wave resonances is formalized within the Hamiltonian approach and the existence of 'long-lived' regimes of evolution is demonstrated. The dynamics of the model perturbed by weak nonconservative effects is investigated in order to identify possible ways of wave pattern evolution. Stationary states are found and their stability is studied. Stability conditions are specified in terms of wave steepness and angles between short- and long-wave components. These conditions correspond to predominantly oblique short harmonics, in other words, wave patterns with specific rhombic orientation of capillary ripples are emphasized by cooperative effect of dissipation/generation and multi-wave resonances.

LABORATORY INVESTIGATIONS OF TWO-DIMENSIONALLY INHOMOGENEOUS CURRENT IFLUENCE ON NONLINEAR SURFACE WAVES

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The variability of various-amplitude surface waves in a field of inhomogeneous currents was investigated in the laboratory tank with use of "contact" and remote devices. Inhomogeneous currents were produced by streamlining of submerged sphere. Surface waves were generated by a wavemaker. The surface deviation in some points of space was recorded by acoustic sensors. The spatial two-dimensional distribution of the surface wave amplitude was reconstructed by results of several experiments. The images of located at the bottom rectangular grid were registered simultaneously at the help CCD camera, that allowed to restore a field of surface wave slopes in spatial area 0.5x0.5 m.
Occurrence of regions of surface wave amplitude increase and decrease is registered and is shown that their arrangement greatly depends on the surface wave frequency and is practically independent of the sphere sizes and the depth of its submersion. The value of surface wave amplitude variability grows at an increased amplitude of surface waves generated by a wavemaker.
Theoretical calculations of surface wave amplitude variability were made for conditions of experiments on basis of model equation obtained by us.

A MODEL OF SPORADIC WIND-WAVE HORSE-SHOE PATTERNS

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A qualitative model of three-dimensional crescent-shaped ('horse-shoe') patterns often seen on water surface in natural basins and observed in wave tank experiments is suggested. The model is aimed at explaining their sporadic nature, physical mechanisms of their selection and their specific asymmetric form. First, the phenomenon of sporadic horse-shoe patterns is studied numerically using the novel algorithm of water waves simulation recently developed by the authors. A system comprising a steep gravity wave under small dissipation embedded into primordial noise is shown to follow the simple evolution scenario: most of the time only one pair of symmetric oblique satellites prevails, the choice of the specific pair being in general case different at different instants.
The explanation of the observed phenomena is based on the consideration of interactions between oblique satellites lying in the domain of the five-wave instability of the basic wave. It is demonstrated that small satellites can affect the system dynamics via the quartic resonant interactions at the same timescale as the quintet interaction with the basic wave. These interactions give rise to a specific selection mechanism: eventualy only a single pair survives in generic situation. The interplay of quartic and quintet interactions and nonconservative effects are shown to be responsible for the specific fronts asymmetry.

ON THE LINEAR APROXIMATION OF VELOCITY AND DENSITY PROFILES IN THE PROBLEM OF BAROCLINIC INSTABILITY

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The linear approximation of density and velocity profiles is compared to more realistic models with vertically inhomogeneous density gradient and non-zero anomalous vorticity (i.e. the non-planetary part of potential vorticity). Calculations based on the parameters of "real-life" currents in the Northern Pacific demonstrate that these effects, acting together, can make baroclinic instability 2.5 - 6 times stronger and dramatically expand the spectral range of unstable disturbances towards the short-wave region (by a factor of more than 20 - 30).

EXPERIMENTAL INVESTIGATION OF EXCITATION OF INTERNAL WAVES IN A TURBULENT STRATIFIED SHEAR FLOW

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The experimental study of dynamics of a turbulent stratified shear current was performed the Large Experimental Tank (20×4× 2 m) with the temperature thermocline-type stratification and the turbulent shear current created by the flow inductor. Profiles of the temperature and flow velocity averaged over the turbulent fluctuations and wave disturbances were measured. For homogeneous in temperature water characteristics of the shear flow created by the flow inductor corresponded to the resulst of the theory of self-similarity developed for free shear flows. In the presence of temperature stratification the stability of the shear flow was studied. In was foung out that in the region above the thermocline the Richardson number could drop below 1/4, i.e. the flow was dynamically unstable. When the flow velocity exceeded some threshold value, strong oscillations were excited. A narrow peak with the maximum frequency 0.05Hz presented in their spectrum. The amplitude of the corresponding quasi-harmonic oscillations depended in a square-root manner on the control parameter (the frequency of spinning of the flow inductor motor, which is proportional to the flow velocity). These two features confirms excitation of a globaly unstable mode in the flow.

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Renormalization of shallow water gravity wave theories to allow deep water

D. CLAMOND

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From the shallow water gravity wave theory, an analytic transformation reconstructs the velocity field in the whole fluid domain. The solution obtained has a non-divergent velocity field, which is not the case of shallow water solutions. The renormalization increases the validity of solution from shallow to deep water : the Korteweg & de Vries waves and the Airy waves are particular limiting cases. The renormalized solution is an unified approximation for short and long waves. The renormalization also improves the accuracy of the solution from small to finite amplitudes.

STRUCTURE FORMATION IN A ZONAL BAROTROPIC CURRENT: A TREATMENT VIA THE CENTRE MANIFOLD REDUCTION

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We apply methods of the bifurcation theory of reversible systems for studying the formation of quasi-stationary spatial structures in a zonal viscous channel flow with a horizontal shear on an $f-$plane. A shifted sine dependence of the zonal velocity on the latitude is assumed. Centre manifold reduction, applied to the quasi-geostrophic potential vorticity equation in a vicinity of the critical value R_c of the Reynolds number R at which a reversible 1:1 resonance occurs, and normal form transformation lead to a completely integrable system of four non-linear ODE's for which a full classification of the bifurcating solutions is available. The zonal solution bifurcates supercritically. The family of bifurcating solutions includes spatially periodic and quasi-periodic solutions, and solutions homoclinic to the same periodic solution at $\pm\infty$ in the zonal direction. The spatially periodic structures corresponding to the periodic bifurcating solutions that persist for the exact system are treated in detail and found to contain closed recirculation regions provided the value of the bifurcation parameter $\mu = (R - R_c)/R_c$ is small enough. Hence, qualitatively, the appearance of such regions in the exact solutions of the equation of motion may be related to the origin of latitudinal distortions of zonal currents and eventually to the development of blocking highs.

COMPLICATED TRAVELLING WAVE SOLUTIONS OF A SYSTEM OF PDE=20 DESCRIBING MEDIA WITH MEMORY AND SPATIAL NON-LOCALITY

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The dynamic equation of state aimed at describing shock loading = afteraction=20 in geophysical media and accounting for the effects of non-locality=20 and memory is proposed. Together with balance equation for mass and = momentum it=20 forms a closed system of nonlinear PDE. A set of invariant (travelling = wave) solutions of this=20 system is investigatied by means of qualitative theory methods and = numerical=20 simulation. The system was shown to possess periodic, quasi-periodic and = stochastic=20 invariant solutions. A fine structure of strange attractors arising in = the=20 dynamic system is studied by means of Poincaré sections technique.=20 An influence of different physical characteristics (relaxation time,=20 coefficient of non-locality etc.) on the wave patterns formation is analysed.

AN ANALYTICAL SOLUTION FOR THE RUN-UP OF WEAKLY 2-D SOLITARY WAVES.

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Very few analytical solutions are known of the Nonlinear Shallow Water Equations (e.g. Carrier & Greenspan, JFM, Vol. 4, pp. 97-109, 1958; Synolakis, JFM, Vol. 158, pp.523-545, 1987). These solutions are attractive as they allow direct computation of flow properties in the near-shore region and are also 'benchmarks' for comparing and testing numerical solvers. However, their drawback rests in their horizontal one-dimensional nature. Recently Brocchini & Peregrine, (JFM, Vol. 317, pp. 241-273, 1996) extended the 'Carrier & Greenspan solution' for the case of weakly-two-dimensional periodic flow. Here we propose an analytical solution which enables easy computation of all the main flow properties (free water surface and both velocity components) associated with the run-up of weakly-two-dimensional solitary waves. A limiting wave amplitude is defined such that breakdown of the solution occurs. A novel analytical solution is also given for interacting solitary waves in shallow waters (multiple-solitary-waves solution) and breakdown conditions are provided in terms of a pair of formulae for both the dimensionless wave heights of the solitary waves and for their initial positions. We suggest the solutions can be used for modelling both the run-up characteristics of a single group of waves (multiple-solitary-waves) and those associated with the run-up of a tsunamis (single solitary wave). Preliminary analysis show that very large run-up is achieved because of the merging of two or more solitary waves which are smaller than the limiting wave.

BISPECTRAL ANALYSIS OF BOUND HARMONICS OF GRAVITY-CAPILLARY WAVES IN A WAVE TANK.

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Measurements of quasimonochromatic and wind gravity-capillary waves (GCWs) were carried out with a laser slopemeter in a wave tank. Phase coupling betweeen decimetre-scale GCWs and their high-order harmonics, including "parasitic" capillary ripples, was studied on the basis of methods of bispectral analysis. The normalized bicoherence function (NBF) was used to determine a quantitative ratio between contributions of free and bound components in the GCW spectrum. For the second harmonics of dominant wind waves this contribution was obtained to be of order 30-40%. NBF also has a wide maximum at high frequencies (larger than 50 Hz), thus showing existence of "parasitic" capillary ripples generated by dominant GCWs.

This work was supported by the Russian Foundation of Basic Research (projects 96-05-65087, 96-02-18027a) and INTAS (project 96-1665).

SAND RIDGES AND BED-FLOW INSTABILITIES ON THE INNER CONTINENTAL SHELF

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Shoreface-connected ridges are sedimentary rhythmic patterns (O(10 Km)) on some continental shelves. Their crests are oblique to the coastline and rotated against the dominant storm current. An explanation of such ridges as emerging from a positive feedback between growing bedforms and the disturbance thereby originated on the currents is investigated. Three different instability mechanisms are identified. First the *transverse slope mechanism*, that is, the offshore deflection of a longshore current by upcurrent oriented ridges and its consequent loss of sediment carrying capacity over the crests due to the slope. Second, the *frictional* and the *coriolis* mechanisms, related to the production of vertical vorticity by the torques due to bottom friction or coriolis force on an uneven sea bottom. Numerical experiments and analytical developments show, after comparison with the morphology, that the transverse slope effect can be considered as the main cause of ridge formation. This has some implications on the long term averaged current and sediment transport during storms on the inner shelves where the ridges are present: the sediment transport should be proportional to the current, and the current should in turn be roughly proportional to the water depth, suggesting a dominant influence of water level gradients rather than wind stresses.

NUMERICAL SIMULATION OF EXPLOSIVE RESONANT INTERACTION OF ROSSBY WAVES

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Multilayer quasi-geostrophic flow in a channel on a beta-plane provides a natural model for baroclinic systems and in particular is well suited to studies of baroclinic instability. The stability criteria have been analysed using both linear and nonlinear theories by Vanneste (1995). In the case where the basic-state zonal flow is uniform within each layer, the regions of parameter space which are linearly stable but nonlinearly unstable are susceptible the explosive resonant interaction of Rossby waves. A detailed analysis of the three-layer model, including an estimate for disturbance eddy energy bounds, has been performed by Paret & Vanneste (1996).
A numerical investigation of explosive interaction has been carried out and is reported here. The emergence of the instability from a random initial disturbance is investigated. The disturbance eddy energy has been calculated and is compared with the bounds of Paret & Vanneste.

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FORMULATION OF ENERGETIC TRIADIC INTERACTIONS IN THE ORTHONORMAL WAVELET REPRESENTATION OF FLUID DYNAMICS

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Traditionally the nonlinear transfer of kinetic energy between orthogonal modes in fluid dynamics has been described by a kind of convolution of Fourier coefficients, known as 'triad interaction'. Triad interaction between wavenumbers n, $-m$ and $m-n$ is known to be constrained by a 'detailed conservation' theorem. Recently Iima and Toh have generalized this description, in the case of incompressible flow, from Fourier to arbitrary orthogonal decompositions such as orthonormal wavelets.
This presentation will generalize their formulation to compressible, hydrostatic flow. Wheras Fourier triads may be associated to wavenumber triangles in 'Fourier space', the 'wavelet triads' correspond to triangles in a position-scale 'phase space'. The case will be made that wavelets provide a better mathematical model of coherent structures than does Fourier, and so waves-turbulence interactions which are local in both scale and position may be better described.

Application of the Wave Theories for Waves Generated in Reservoirs by Earthquakes.

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In prediction of seismogenic waves ("tzunami") in reservoirs problem of avaliability of small amplitude wave and shallow water theories is important from the point of view of engineering applications. Criterial conditions of divergency of wave parameters calculated within limits of both above theories are developped based on theoretical considerations as well as on laboratory tests data.

Nonlinear characteristics of ocean wave observations

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The nonlinear characteristics of 420 temporally disparate data sets of ocean wave height observations (2 hours, 17 minutes each at 1 Hz) collected off the California, USA coast were analyzed using algorithms developed from studies of chaotic systems. A significant finding is that the dynamical characteristics of the waves are independent of the wave height and that the embedding space is the same for all the data sets. The global embedding dimension (degrees-of-freedom), d_E, is consistently six or seven, as is the local dynamical dimension, d_L, The largest of the d_L Lyapunov exponents (λ_1), a measure of future uncertainty, hence predictability, varies widely, and is also independent of the wave height. Thus, λ_1 is a good candidate for a wave classification metric. The prediction horizon, derived from λ_1, has values ranging from near 0 seconds to almost 80 seconds. The consistent embedding space and the positive Lyapunov exponent indicate it is appropriate to treat ocean waves as chaotic. Data from hurricane Camille is used to illustrate how the λ_1 varies with time, providing insights into the time scales over which the dynamics change.

CAPTURED BY FLOWS NONLINEAR ROSSBY WAVES IN THE EARTH'S IONOSPHERE

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AbstractConstruction of the theory of the nonlinear Rossby waves in conductive and nonconducting layers of the atmosphere in the prersence of zonal and meridional circulation is attempted for the first time. The analytical expressions describing dynamics of neutral and conductive vortices are obtained. Structural peculiarities of vortices depending on quantity of magnetic gyroscopic forces are considered. Possibility of excitation of linear and nonlinear Rossby waves due to the shift of the geographical and the geomagnetic coordinates is considered. Results of developed theory are compared with data of observations.

FREE NONLINEAR VORTICAL ROSSBY STRUCTURES IN THE EARTH'S IONOSPHERE

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Abstract The question of the influence of the interaction between ionized component of the ionosphere and the Earth's magnetic field on the properties of the Rossby waves in all (D, E and F) layers of the ionosphere is considered for the first time. In this case, the medium is under the action of not only spatially inhomogeneous Coriolis force but also under spatially inhomogeneous Lorentz force. This leads to the new effects and properties of the Rossby waves. The magnetized Rossby waves and vortices are found in the E-layer. The real natural mechanism which can lead to the inversion of the propagation direction of free, noncaptured by flows, Rossby waves is indicated. The damping decrement due to the induction (magnetic) inhibition of the Rossby waves in the F- layer is defined. The original nonlinear equations describing the vortical formation dynamics in the D, E and F layers are obtained.

THE HAMILTONIAN DESCRIPTION OF WAVES IN A STRATIFIED ROTATING FLUID

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A Hamiltonian theory of nonlinear interaction of surface Kelvin and gravity waves in a layer of rotating fluid, of internal and surface waves in a double layer ocean, and baroclinic Rossby waves on a sphere is constructed. The transformations of ordinary physical variables to normal canonical variables are found for internal and surface waves in a double layer model of the density distribution. These normal variables are used for calculation of the coefficients of three-wave and four-wave interaction these waves, for analysis of stability of quasimonochromatic trains of surface waves with respect to self-modulation and self-focusing, and for obtain the solution for the solitary surface waves. On the basis of the theory developed the self-action of baroclinic Rossby waves in a spherical layer of rotating fluid, the decay instability of short surface Kelvin waves in the presence of a given long gravity wave, as well as stabilization of the decay instability due to phase mismatch of the interacting waves on cubic nonlinearity of the medium are studied. The growth rates of the decay and modulational instabilities are estimated for typical parameters of the oceanic waves.

NONLINEAR INTERNAL WAVES OF ARBITRARY LENGTHS IN THE OCEAN WITH THE DENSITY JUMP

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Dynamics of the interface three-dimensional perturbations in the two-layer liquid bounded by gently sloping rigid lid and bottom is studied. In the system with horizontal lid and bottom the new equation for plane steady-state waves running in the direction of the x-coordinate increase has the following form:

$$(U^2 - g\delta A_\xi)\eta - \beta\frac{U^4}{g_+^-}A_\xi\frac{d^2\eta}{d\xi^2} - \zeta U^2\left(1+\frac{1}{2}A_\xi\right)\eta^2 + \gamma\beta\frac{U^4}{g_+^-}A_\xi\frac{d^2\eta^2}{d\xi^2} -$$

$$-\frac{\delta}{2}U^2A_\xi\left[\left(\frac{d\eta}{\delta\xi}\right)^2 + \frac{7U^4}{(g_+^-)^2}\left(\frac{d^2\eta}{d\xi^2}\right)^2\right] = 0, \qquad A_\xi = 1 - \frac{2}{3}\beta\frac{U^2}{g_+^-}\frac{d^2}{d\xi^2}.$$

Here $\xi = x - Ut$, t is the time, U is the speed of the wave propagation, g is the acceleration of free fall. The coefficients δ, β, ζ, γ and g_+^- depend only on the geometric and physical parameters of the system. This equation has the solution of the Stokes wave type which coincides with the well-known expansions in the limits of deep and equal shallow layers. Some solitary and periodic solutions of the model differential equation were found numerically.

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THREE-DIMENSIONAL INTERNAL GRAVITY WAVES : A HIGH-RESOLUTION NUMERICAL STUDY

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We present high resolution numerical results on the dynamics of three-dimensional internal gravity waves in a stably stratified Boussinesq fluid. Our study focuses on the evolution of large scale plane monochromatic internal waves in time, their instabilities, their breaking and the resulting stratified turbulent regime. Of particular interest is the production and interaction with an essentially three-dimensional non-propagating component of the motion associated with potential vorticity.
In a prior two-dimensional study it was found that provided the initial wave amplitude is small enough, the initial large scale internal wave is destabilized by resonant wave-wave interactions. The final breakdown of the wave field occurs via a global shear layer instability. Although the resonant interaction instability mechanism is likely to be conserved for small initial amplitude internal waves in three dimensions, the later stages of the loss of wave coherence processes are expected to display a genuinely three-dimensional behavior, the caracteristics of which shall be presented during the talk.

EVOLUTION OF AN ENSEMBLE OF VORTICES ON A BETA-PLANE IN THE EQUIVALENT BAROTROPIC MODEL

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The classical feature of two-dimensional turbulence is the formation of coherent vortices from the initially random field. The merging of vortices of the same sign provides the spectral transport of energy to larger scales. There is a tendency of spectral transport of energy toward the Rossby radius scale if to consider the equivalent barotropic model. A beta-effect produces additional length scale that determines the boundary between weak (wave-like) and strong turbulence. In this study we consider the behavior of the ensemble of vortices spread uniformly over the area of integration. We assume that vortices emerged earlier and have the scale close to the Rossby radius. We use a Poison statistic to generate the initial field consisted of Gaussian vortices. The turbulent beta-scale and the Rossby radius have the same order of magnitude in our simulations. The potential vorticity equation is integrated numerically by the quasi-spectral method in the squared domain with periodical boundary conditions. Some vortices disappear at the beginning of integration due to the merging or under the influence of strain. Remaining vortices together with radiated Rossby waves form the slow evolved turbulent field. It is remarkable that the energy of vortices depends only on the value of its meridional displacement from the initial position and its initial scale. The dependence is the same as for the single vortex of the same shape freely propagating on a beta-plane. Thus we can calculate the energy of vortices based on their trajectories. Next we compare the evolution of each vortex from the ensemble with the freely propagating single vortex of the same shape for the same time of integration. We found that the freely propagating vortex displaces for a larger distance along the meridian. Thus a vortex from the ensemble has smaller energy lost for the same time. It means that vortices in turbulent field not only radiate Rossby waves but also extract energy from the wave field. The possibility of energy flux from a plane wave to a single vortex we showed earlier. The looping of trajectories of vortices and the time-space spectra of the wave field gives evidence of the energy exchange between vortices and waves in turbulent flow.

LONG TIME EVOLUTION OF GRAVITY WAVES

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At least four theoretical avenues for the non-linear prediction of long time, conservative, wave evolution exist: kinetic equations, narrow banded PDE of the cubic Schrödinger type (NLS), narrow banded PLUS (e.g. Dysthe eq.), fully non-linear computations (FNL). Careful systematic comparison between these methods and with experiments is lacking. Here we report some results showing comparisons between several theoretical predictions of the evolution of a system beginning as a carrier wave plus small closely spaced side-bands, $(\omega_c \pm \delta\omega)$. The FNL is able to predict wave overturning and breaking and we have made a comparison of the breaking predictions with observations in our systematic wave tank experiment (see our companion paper here by Tulin & Waseda). The agreement is very good in tracing out the breaking boundary in $\delta\omega$, ka space and, therefore, the FNL has been taken as a benchmark. Evolution results are contrasted with those from three different weakly non-linear models: Krasitskii (5 waves: ω_c, $\omega_c \pm \delta\omega$, $\omega_c \pm 2\delta\omega$), NLS; Dysthe. The rank order of performance was: Krasitskii (5), Dysthe, NLS. The success of Krasitskii (5) is due to the additional waves at $\omega_c \pm 2\delta\omega$; without it Krasitskii (3) fails like the NLS. As the breaking condition is closely approached large deviations suddenly appear between the FNL and Krasitskii (5), best of the analytical methods, perhaps indicative of a failure of the weakly non-linear approximation there.

ON THE THREE-WAVE INTERACTIONS IN THE ATMOSPHERIC TIDAL SYSTEM

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The influence of the upward propagating solar migrating tide on the thermosphere is considered by the numerical modelling methods.The calculations show that the propagation of this tide excites the nonmigrating tides in the lower thermosphere.These diurnal and semidiurnal nonmigrating tides have the significant contribution in the global thermospheric variations. It is assumed that basic mechanism of the nonmigrating tides generation is determined by the three-waves interactions in the tides - mean atmospheric state system. The wave vector components of the diurnal and semidiurnal nonmigrating tides generated in the lower thermosphere have the agreement with the resonant relations in the three-wave system. Some model based on periodical solutions of the three-wave system is proposed and compared with the numerical one.

The Flux Vector Splitting Method Application for the Numerical Solution of Shallow Water Equations .

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Implicit and explicit finite - difference schemes based on the Flux Vector Splitting (FVS) method for numerical solution of hyperbolic equations system describing water motion in open channels are built. The convergence of the above solutions with smooth periodic solutions of the corresponding boundary-values problems is proved. The computational formulae are simple and handy. The schemes possibilities are illustrated by numerical tests.

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A SEMI-LAGRANGIAN FINITE ELEMENT BAROTROPIC OCEAN MODEL

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A barotropic two dimensional flow is simulated by discretizing the inviscid shallow water equations using the finite-element and semi-Lagrangian methods on unstructured triangular meshes. The treatment of the nonlinear Rossby waves is fourth order accurate by using a kriging interpolation scheme. Two experiments are performed in the Gulf of Mexico to test the ability of the model to simulate slowly-propagating nonlinear Rossby modes. We simulate the trajectory of a typical anticyclonic eddy which is shed off the Loop Current. Firstly, the model is run as a reduced-gravity model with parameters set to correspond to the first internal vertical mode of a baroclinic model. Secondly, the external mode is run with realistic bathymetry. The residual circulation over a topographically irregular coastal channel driven by a time-varying wind stress is also examined. A last test reproduces the propagation of a Rossby soliton on an equatorial β-plane.

NONLINEAR STABILITY AND INSTABILITY OF ZONAL WIND IN THE ATMOSPHERE

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Arnol'd's nonlinear stability theorems are applied to study the nonlinear stability and instability of zonal wind in middle and high latitude atmosphere. The relationship between the stream function and the potential vorticity on the 500 hPa isobaric surface is investigated. The results demostrate that Arnol'd's second theorem is more important than the first theorem in the study of nonlinear stability of quasigeostrophic motions in the atmosphere, since the stream function decreases with increase in the potential vorticity, which satisfies the second theorem rather than the first one.

On the basis of the above analysis, a method of the optimal determination of the "basic flow" is proposed to study the nonlinear stability and instability of zonal wind in the middle and high latitude atmosphere. The results show that the stable flows in the synoptic chart satisfy the Arnol'd's second theorem, and the unstable flows destroy the conditions of Arnol'd's second theorem. All these studies demostrate that Arnol'd's second stability theorem is of importance in the diagnosis of the stability and instability of atmospheric motions.

NORMAL FORMS FOR SHALLOW WATER EQUATIONS

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Several normal forms is considered for the shallow water equations. A first form is the Poincare normal form. A second form is a cosymmetric normal form. A third form is the Hamiltonian form.
The Poincare normal form can be extented for partial differential equations, that have linear ordinary equations, as a main part. Poincare normal forms of the shallow water equations on beta-plane and for large scale (with respect to Rossby radius) are found.
Cosymmetric normal form of gradient systems with a skew-symmetric bracket and a definite determining function (functional) is constructed, This form guarantees an exact conservation of energy. The cosymmetric form of the shallow water equations is found.
A asymptotical version of the Darboux theorem for the field Hamiltonian systems is proved. The Poisson brackets of the equation for the Rossby waves, the shallow water equations on beta-plane and the one-dimensional baroclinic fluid are considered as examples of an theorem application.
A set of canonical equations for Rossby waves are constructed. Using resonance theory, the Hamiltonian system for Rossby and inertia-gravity waves are obtain, that describes the main resonance interactions only. It is found that an asymptotical normal form of the Poisson bracket for the one-dimensional baroclinic fluid is a direct product of the canonical and zero brackets.

SHALLOW WATER SURFACE WAVES: THE WHITHAM EXPANSION, KDV HIERARCHY AND LIE TRANSFORM

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The Korteweg-de Vries equation for water waves arises from a first order multiscale expansion of the Euler equation in the case of irrotational flow and unidirectional waves. If terms of second order are retained in the expansion, a physically important equation, still unexplored, is derived. This equation, referred to as the Whitham II equation, describes shorter and higher waves with respect to the KdV equation but has the big disadvantage of not being integrable in the sense of the inverse scattering transform. Following the idea of Kodama (Physics Letters, 112A, 1985), we show that by applying a Lie transform (a near identity transformation), the Whitham II equation reduces asymptotically to the second equation in the KdV hierarchy which is known to be completely integrable and allows a representation of the wave amplitudes in terms of theta functions for periodic boundary conditions. We investigate numerically both equations using a pseudo-spectral method and discuss the physical meaning of the Lie transform. The possibility of applying the Lie transform directly to experimental data and successively analysing them through the inverse scattering method is also addressed.

TOWARDS NUMERICAL RESOLUTION OF THE PERIODIC INVERSE SCATTERING FOR THE KADOMTSEV-PETVIASHVILI (KP) EQUATION

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I study numerically the Floquet structure for the spectral eigenvalue problem for the KP equation. I construct the Bloch eigenfunctions and study their behavior for a class of periodic potentials as candidate solutions of KP. A number of surprising results arise as a consequence of this study. First, in analogy with the spectral problem for the KdV equation, I am able to construct the algebraic loop integrals of KP which lead to estimates of the period matrix, wave numbers, frequencies and phases of the inverse problem in terms of theta functions. I discuss a number of numerical examples for which I am fully able to construct the spectrum and then to reconstruct the input potential. These results suggest that the Floquet problem provides a convenient way to parameterize uniquely the inverse scattering transform spectrum and to construct solutions to KP. Furthermore, it seems likely that future studies will be able to use these results for the analysis of ocean wave data in order to study the nonlinear behavior of directionally spread shallow water wave trains.

TERMINAL RADIATIVE DAMPING OF A SOLITARY WAVE IN ROTATIONAL SYSTEMS

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The evolution of a solitary wave under the action of rotation is considered within the framework of the rotation-modified Korteweg-de Vries equation. Using an asymptotic procedure, the solitary wave is shown to be damped due to radiation of a dispersive wave train propagating, near the solitary wave, with the same phase velocity as the latter. Such a synchronism is possible because of the presence of rotational dispersion. The law of damping is found to be "terminal" in the sense that the solitary wave disappears in a finite time. The radiated wave amplitude and the structure of the radiated "tail" in space-time are also found. Some numerical results are given which confirm the approximate theory.

SOME REMARKS ON THE PROBLEM OF WIND WAVE GENERATION IN A ROTATIONAL FLOW

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The question of *how* the wind blowing near the free water surface generates waves remains a central problem in wind-wave researchs, despite the large amount of theoretical and experimental work. We consider the problem in the framework of the mechanism of wave generation by intense events (bursts): irregularities, localized in space and evolving with time, and moving in a *rotational* flow near the air-sea interface. In the framework of the proposed mechanism, the analytical expressions for the dispersion relation $\omega_k = \omega[k, U(0), rot\, U(0)]$ of the generated waves and for the spectral distribution $S(k)$ are obtained. It is shown that in the framework of the model the spectrum $S(k)$ of short waves is directionally distributed, i.e. exhibits a peak at k_{max}, and has a rapid bluff at wavenumbers less then k_{max}. It is shown that the frequency corresponding to this dominant peak depends on the characteristic velocity scale U. The calculations are compared with laboratory data. A satisfactory agreement between the predictions and the experimental date was found.

VARIABLE-COEFFICIENT ROTATION-MODIFIED EXTENDED KORTEWEG-DE VRIES EQUATION FOR OCEANIC INTERNAL WAVES

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A nonlinear model for the evolution of the internal tide in the shelf zone is developed based on the rotation-modified extended Korteweg-de Vries (gKdV) equation. This model includes quadratic and cubic nonlinearity, dispersion, effects of the Earth's rotation, and weak horizontal variability of the background stratification. The issue of the correct definition of the coefficient of the cubic nonlinear term is considered. Several model examples of the density stratification are used to obtain analytical expressions for all coefficients of the basic equation. The solitary wave transformation in a zone of variable sign for the coefficients of either or both the quadratic and cubic nonlinear terms is studied. The nonlinear vertical modal structure of these internal waves is also discussed. Results of numerical simulations show that the combined action of nonlinearity and rotation leads to interesting features in the wave forms including solitary waves of either polarity, thick solitary waves, and sharp waves with step-like structure.

SWASH ZONE MEASUREMENTS IN A WAVE FLUME

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Wave set-up has been measured on impermeable fixed plane beaches by a number of researchers, from Bowen et al (1968) to Stive (1985). All the results refer to beach slopes ranging between 0.022 and 0.1. Starting from the outcomes resulting from research up to now, we have carried out new experiments on a impermeable beach with constant slope and with different values of the surf similarity parameter. The main aim of these experiments is to take detailed measurements in the swash zone, where strongly non-linear processes occur, and to compare the results with some existing models. The experiments took place in the wave tank (0.8 m x 0.8 m x 50 m) of Florence Department, equipped with second order generation. The measurements refer to free surface profiles, to run-up and run-down limits and to fluid velocities. The specific equipment used were twin wire water level meters, pressure transducers, image analysis, LDA and micro propeller. All the tested waves are monochromatic, with possible future extension to irregular waves.

EFFECT OF AIR TURBULENCE ON THE BENJAMIN–FEIR INSTABILITY OF GRAVITY WAVES ON DEEP WATER

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It is well known that weakly nonlinear wave trains of gravity waves on deep water are unstable to modulational perturbations. This type of instability (Benjamin and Feir instability) is due to the growth of sideband perturbation and produces an amplitude modulation of the original wave train. The role of this resonance is of primary importance in the evolution of wavefields. There is so far no numerical experiments concerning the effect of air turbulence on the nonlinear stage of this instability. In this work, we investigate numerically effects of turbulent air flow on the growth rate of the Benjamin and Feir instability. The numerical model consists essentially of two parts: hydrodynamic part for surface gravity waves, and aerodynamic part for air flow. The potential theory is used to solve the evolution of gravity waves on deep
water. The velocity and pressure distribution in the air flow over waves is governed by the Reynolds averaged Euler-equations for an incompressible flow. Different turbulent closure schemes are used to parameterize the turbulence. The coupling between the air flow and waves is made through the dynamic and kinematic conditions at the free surface. The present numerical experiment will be compared with laboratory experiments on mechanically generated waves with wind blowing over them, which showed that gentle wind tends to enhance growth whereas strong wind suppress it.

PASSING OF AN INTERNAL SOLITARY WAVE OVER A STEP

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We study the effect of a sudden change of depth upon an incident internal solitary wave. We installed a shelf, 70 cm high and 8 m long in the 13 m diameter rotating tank. The slope has a cos2 shape and is 50 cm wide. A 5 m long internal solitary wave generator is located at some distance from the slope and the incidence angle can be varied. The tank is filled with a two-layer system of salted and fresh water and the interface height variations with time are recorded with a 0.5 mm accuracy. In non-rotating fluid and for small (weakly nonlinear) waves, the refraction angle agree with the analytical model developed by Pinettes et al. (Fluid Dyn. Res.16 (1995) 217-235), but for larger amplitude solitary waves the refraction angle is significantly larger than predicted. It appears that this is due to nonlinearity and that rotation effects are one order of magnitude less important than nonlinear effects. Special attention is also concentrated upon the local perturbation which moves along the shelf break. This work is a contribution to MAST3-MORSE- CT95-0027-Programme.

SOME PROPERTIES OF WIND WAVES PROPAGATING ON SURFACE CURRENTS

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Growing demand of remote sensing prompt us to re-examine the measurable properties of wind waves on the "real" surface currents. Both the laminar and turbulent types of current profiles with the parameters taken from laboratory and field measurements were investigated. In the result of asymptotic and numerical analysis of linearized Rayleigh boundary value problem it was found that the week flow approximation based upon smallness of the current to wave phase velocity ratio introduced by [Stewart & Joy, 1974] gives surprisingly good results for real part of dispersion relation well beyond the domain of its asymptotic validity. Our work closes long debated question on the possible role of Miles' type instability: being very sensitive to the specific shape of profile it was found that for the typical turbulent profiles the growth rates are four orders less than for laminar and model profiles used earlier for estimations, and thus are below the viscous threshold. Making use of semi-Lagrangian reference frame it was also found that wave kinetic-to-potential energy ratio may deviate up to several tens of percents from unity, the maximal deviation being reached when the wavenumber times effective current thickness is of order of unity.

LONG-TERM EVOLUTION OF INTENSE BAROTROPIC VORTEX ON BETA-PLANE

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Scaling and numerical analysis of the barotropic vortex on beta- plane reveals that the vortex passes through the following stages: 1) development of the secondary dipolar circulation (beta-gyres) forcing the vortex to move; 2) intensification of the quadroupole and secondary axisymmetrical components and the vortex deceleration; 3) the vortex decay and destruction. To describe the second stage we developed for an intense vortex with piecewise constant potential vorticity a theory taking into account conservation of the vortex energy and enstrophy. The theory allows to calculate the quadroupole and axisymmetrical corrections and the correction to the translation vortex speed. In accordance with the theory the vortex deceleration is induced by the secondary beta-gyres resulting from the interaction between the primary beta-gyres and the quadroupole and secondary axisymmetrical corrections. All analytical results are in a good agreement with numerical experiments carried out by other authors. Using the conservation laws we obtained that the vortex lifetime is directly proportional to the vortex amplitude and inversely proportional to the group velocity of Rossby waves. The lifetime of the open ocean eddies (oceanic rings) is approximately equal to 130 (650) days. Analysis of the residual produced by the asymptotic solution explains why the solution is a good approximation for times much longer than the formal time of its applicability.

SEA SURFACE MANIFESTATIONS OF LARGE-AMPLITUDE INTERNAL WAVES DURING DIFFERENT WIND CONDITIONS

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Observations were made near the Mascarene Ridge in the Indian Ocean under different sea conditions (winds 8-10 m/s and calm weather). In-situ and radar observation techniques were used to measure internal waves from a towing or a drifting vessel. Sharply distinguished internal waves of three main types were found, with amplitudes up to 70-90 m. The origin of the 1st and 2nd internal wave types was connected with an internal hydraulic jump on the lee side of the sill. The origin of the 3rd type was related to the nonlinear evolution of the internal tide as it radiated from the sill edge to the open ocean. All of these waves had strong interactions with the sea surface, and were clearly seen in the radar images. Internal waves manifested as a single wide band (for solitary waves) or as sets of periodic striations (for internal wave packets). The radar image of the solitary waves varied, depending on the background sea conditions. In the case of calm weather, solitary waves appeared as a single bright band on a dark background, while for wind-wave conditions, the waves appeared as a single dark band on a lighter background. An explanation of the features is offered; our hypothesis is that wind waves are modulated by the orbital currents of internal waves. Correlations between the position of the characteristic band on the sea surface and internal wave phase are revealed and demonstrated by the observed examples. Evidence of generation of intense surface waves by a huge solitary internal wave during absolutely calm weather is presented in detail.

HAMILTONIAN APPROACH TO THE DERIVATION OF EVOLUTION EQUATIONS FOR NONLINEAR WAVE-PACKETS IN UNSTABLE MEDIA

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The evolution equations for weakly nonlinear wave-packets propagating in unstable medium are considered. It is shown that the commonly used normal variables are not appropriate for description of marginally stable wave-packets. For a broad class of Hamiltonian dynamical systems we construct the canonical variables based on the linear combination of eigenvectors corresponding to the two weakly coupled modes. Using these variables we derive evolution equations both for weakly unstable and marginally stable wave-packets. Also derived are the three-wave resonance equations including cases when one of the interactiong waves is marginally stable or weakly unstable. As a particular case we obtained that the participation of a marginally stable wave in the resonance interaction can lead to the explosive instablily the growth rate of which exceeds that one for the case when all the interacting waves are stable. The results are applied for investigation of resonance wave interactions in the n-layer model of the atmospheric stratified shear flow. The Hamiltonian approach simplifies essentially the calculation of the interaction coefficients which is formidable when we consider the intermodal interaction.

NONLINEAR DYNAMICS OF A BAROTROPIC WAVE PACKET IN A WEAKLY SUPERCRITICAL ZONAL FLOW

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Finite-amplitude dynamics of a barotropic wave packet in a weakly supercritical horizontally sheared zonal flow in the presence of a critical layer is studied within the beta plane approximation. Small supercriticality defined through the gradient of the planetary vorticity and the Eckman dissipation parameter specifies the narrow bandwidth of the instability range. An asymptotic approach involving expansions with respect to the supercriticality and spectral bandwidth has been elaborated to extend the nonlinear critical layer theory on the case of the wave packet with a slow spatial variation. The system of two coupled equations governing the evolution of the complex wave amplitude and potential vorticity inside the critical layer is derived. For the solution of the problem a numerical scheme including the Fourier series expansion along the flow direction and the finite-difference approximation across the critical layer is realized for the periodic boundary conditions corresponding to the annular zonal flow. The problem is reduced to the Ginzburg-Landau equation whenever the supercriticality is small enough for the critical layer to be in a viscous regime. In this case well known from the laboratory modeling competition between spectral component of the wave packet has been revealed. As the supercriticality increase the system demonstrates transition to chaos. The route to chaos turns out to be very close to that predicted by the Ruelle-Takens theory.

NONLINEAR DEVELOPMENT OF UNSTABLE DISTURBANCES ON THE MAGNETOFLUID FREE SHEAR FLOW WITH A PARALLEL MAGNETIC FIELD

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A study is made of the spatial downstream evolution of a weakly-unstable disturbance excited by an external source of a frequency ω close to the frequency of a marginally stable (neutral) mode, in a mixing layer of almost perfectly conducting, nearly inviscid fluid with an uniform parallel magnetic field. The nonlinear dynamics of such a disturbance is governed largely by two critical layers, i.e. by two narrow regions on the flow profile $v_x = u(y)$ near critical levels $y = y_j$ ($j = \pm 1$), on which the resonance condition $u(y_{\pm 1}) = c \pm c_A$ is satisfied. (Here c being the wave's phase velocity corresponding to the neutral mode, and c_A is the Alfven velocity.)
A nonlinear integro-differential evolution equation is derived for a complex amplitude of the disturbance, which holds good for all possible regimes of critical layers, and its solutions are analyzed (numerically and analytically) with different relationships between problem parameters. It is shown that the nonlinearity can play both a stabilizing and destabilizing role depending on the magnitude of the initial magnetic field and on the degree of supercriticality of the wave. The structure of the perturbed magnetic and velocity fields is also investigated.

FORCING OF SOLITARY WAVES BY THE DEFORMATIONAL LONG-WAVE INSTABILITY

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The one-dimensional version of the equation governing the flows in a rotating fluid layer heated from below with a deformable upper stress-free surface is numerically studied. As was shown in our previous paper nonlinearity in beta-term gives the finite-amplitude, periodic in spatial coordinate solutions. This nonlinearity is not sufficient for realization of solitary-waves. Here we account for the next terms in the expansion of negative diffusion coefficient in the deformation of the upper stress-free surface. In this case in some ranges of parameters solitary-wave solutions can exist.
The establishment of solitary-wave solutions is due to appearance of strong inelasticity during encounters of separate pulses. So we reproduce in our one-dimensional simulations the effect which takes place in two-dimensional case: catching by the strong vortex of the weak ones.

EVIDENCE OF NON-LINEAR INTERNAL WAVE PACKET INTERACTIONS AT A SHELF EDGE

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Remotely sensed and in-situ observations of internal waves were made at the Malin shelf edge during SESAME (Shelf Edge Studies Acoustic Measurement Experiment), in conjunction with SES, in August-September 1996. SAR imagery indicates the existence of a number of individual wave packets propagating upslope and on-shelf. These originate from both local (shelf edge) and distant sources. Interactions occur between the wave packets, sometimes resulting in the type of resonance predicted by T Maxworthy (J Fluid Mech, 96, 1, 47-64, 1980). Maxworthy showed that this resonance only occurred when the angle between the packets exceeded a critical angle. This angle is calculated for the SESAME region, and used to interpret the data. In-situ data also shows multiple packets, each recurring on tidal cycles. Possible in-situ evidence of resonant internal waves is displayed from thermistor chain data. Techniques of modelling the non-linear interactions are discussed. It is suggested that these three-dimensional processes are important for internal wave modelling.

LABORATORY OBSERVATIONS OF WAVE GROUP EVOLUTION, INCLUDING BREAKING EFFECTS

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The non-linear evolution of deep water wave groups, which are initiated by unstable three-wave systems, have been observed in a large wave tank (50 m long, 4.2 m wide, 2.1 m deep), for waves 1.0 - 4.0 m long, initial steepness $\epsilon = 0.10$ - 0.28, and normalized sideband frequency differences, $\delta\omega/\epsilon\omega$, 0.2 - 1.4. Minimizing the effect of background disturbances on the evolution, new observations were made which extends the pioneering work of Lake et al. and of Melville. Foremost, near recurrence without downshifting was observed without breaking, despite a significant but reversible energy transfer to the lower sideband at peak modulation; complete recurrence was prevented by the spreading of discretized energy to higher frequencies. Strong breaking was found to increase the transfer of energy from the higher to the lower sideband and to render that transfer irreversible. The endstate of the evolution following strong breaking is an effective downshifting of the spectral energy, where the lower and the carrier wave amplitudes nearly coincide. An explanation of the sideband behavior was given based on wave energy and momentum considerations, including the separate effects of energy and momentum loss due to breaking, and transfer to discretized higher frequencies, which was almost universally observed.

NUMERICAL INVESTIGATION ON THE NONLINEAR STABILITY AND INSTABILITY OF QUASIGEOSTROPHIC MOTIONS

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Nonlinear stability and instability of quasigeostrophic barotropic motions are investigated numerically, based on the theoretical results of Arnol'd's nonlinear stability criteria. The domain under consideration is a zonal periodical channel $(0, X) \times (0, Y)$ on a beta plane, and the basic flow of the stream function is $\Psi = A(cosky + sinky)$. The initial disturbance stream functions are $\psi = B(cos2m\pi x/X + sin2n\pi x/X)sinl\pi y/Y$, where m, n and l are any integers.
By integrating the governing model, the behaviors of the initial disturbances to the stable or unstable basic flows are investigated. The main results are as follows: 1. For a basic flow which satisfies the Arnol'd's stability criteria, no matter what kind of initial disturbances are superposed on it, the disturbance energy and disturbance potential vorticity are conserved in time. Besides, the behavior of the disturbance field is characterized by a traveling fields in the zonal direction, without deformation and "blow up". 2. For a certain disturbance field superposed on a basic flow destroying the Arnol'd's stability criteria (and might be nonlinearly unstable), not only the disturbance field deform and blow up apparently, but also the disturbance energy and disturbance potential vorticity increase rapidly in time, and saturate after a period of time.

MODULATION OF SHORT SURFACE WAVES RIDING ON A SWELL WAVE UNDER THE TURBULENT WIND. QUASI-LINEAR MODEL OF THE GROWTH RATE MODULATION

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The model of modulation of short waves riding on a swell wave is developed explaining the main properties of the hydrodynamic modulation transfer function (MTF). They are as follows: 1) the magnitude is equal to 5-15 increasing with the long wave period and decreasing with the wind speed; 2) the phase varies considerably but is frequently near zero.
The model is based on considering of modulation of the short wave growth rate caused by variation of conditions of the wave generation by wind along the phase of the long wave. When calculating the growth rate and its modulation, the nonlinear effects of the wind-wave interaction is taken into account. The main effect is deformation of the mean velocity profile, which can be reduced to increasing of the roughness heigth. In the presence of the swell wave the rougtness height is modulated. This effect is calculated within the quasi-linear theory based on the assumption of random phases of the wind waves. The effect of the wave disturbances of turbulent stresses is described within the eddy viscosity model. The amplitude and phase of the hydrodynamic MTF are calculated within the relaxation model. The results of the MTF magnitude and phase calculations are in agreement with the available experimental data.
This work was supported by the grants INTAS-96-1665 and RFBR (project code 96-05-65128).

THE EFFECT OF NON-UNIFORMITY OF A WAVE TRAIN ON THE MECHANISM OF BENJAMIN-FEIR INSTABILITY

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We consider a weakly nonlinear, non-uniform Stokes wave train of finite amplitude on deep water. The non-uniformity, characterized by slowly varying amplitude, wavenumber and frequency, modifies the stability properties of the wave in comparison with the uniform case. Based on analytical methods, it is shown that such a wave becomes stable under certain conditions. One of these is a sufficient degree of non-uniformity. This differs essentially from the case of a uniform Stokes wave, which proves to be definitely unstable (Benjamin & Feir). The present results are based on the usual linear stability analysis. However, these are not modified by the incorporation of weakly non-linear, periodic wave perturbations. Furthermore, the analysis (valid for this specific example) is readily applied to a greater variety of non-uniform, dispersive waves.

MASS TRANSPORT INDUCED BY A SLOWLY MOVING CORRUGATED PLATE IN A VISCOUS ROTATING FLUID

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The mean mass transport induced by a moving large plate with corrugated bottom on top of a viscous rotating fluid is investigated theoretically using a Lagrangian description of motion. The bottom corrugations are sinusoidal with infinitely long crests and small amplitudes. The plate velocity is slow enough for a suitably defined fluid Reynolds number R to be small. The solutions are written as a two-parameter series expansion in R and the nondimensional amplitude ε. The solutions to $O(R^1\varepsilon^2)$ yield the interaction between the basic shear flow (an Ekman current, or a Couette flow in the nonrotating case) and the nonlinear displacement field due to the corrugations. The steady mean solution to this order is obtained, and the results show that the analytical method applied by Wang (1978, 1988) has severe shortcommings in predicting the velocity field. The deflection angle α between the surface stress that drives the plate and the drift direction is compared to the corresponding deflection angle α_0 for a flat plate. It is found that $\alpha > \alpha_0$ for nondimensional corrugation wave numbers larger than 2.25, with a deflection angle that becomes larger the more the drift is aligned along the striations. For smaller wave numbers, $\alpha < \alpha_0$, with a minimum value when the motion of the plate is deflected about 23^0 off the cross-striation direction.

NP4

EXPERIMENTAL STUDY OF THE STABILITY OF DEEP WATER WAVE TRAINS INCLUDING WIND EFFECTS

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An experimental investigation on the Benjamin-Feir instability of non-linear deep water wave trains including wind effect is reported. The experiment was conducted at the OEL wind-wave tank (50 m long, 4.2 m wide, 2 m deep and 1.5 m air passage height) with a fully computer controlled mechanical wave-generator exploring the parameter space; steepnesses (ak=0.133, 0.175, 0.20, 0.24); sideband frequencies ($\delta f/f/ak$=0.34~1.1); wind speeds (1.8-13.1 ms^{-1}). The initial growth rate was estimated for 1.5 m wave from spectral measurement at 11 stations spread along the tank (1.8-41.4 m). Both "seeded" experiment where the wavetrain was initially modulated and "un-seeded" experiment where the wavetrain was initially un-modulated, were conducted. The "seeded" experimental result showed a smaller wind effect in the growth rate as reported earlier by Bliven et al. The "un-seeded" experimental result revealed that the natural selection of the sideband strongly depends on the wind speed, but the resulting growth rate was still well predicted by the inviscid theory based on Krasitskii. From both Bliven et al.'s and our result, we conclude that the main effect of the wind in the instability comes from the selection of the sideband, rather than the modification of the inviscid growth due to viscous effect alone.

NP4 Nonlinear waves, coherent structures and natural hazards

02 Fluctuations, self-organization and natural hazards (co-sponsored by NH)

Convener: Moiseev, S.S.
Co-Convener: Mendes-Victor, L.A.

A Nonlinear dispersive wave model for Tsunami propagation

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The description of the Tsunami run-up is of greatest importance for Tsunami zonation and evaluation of Tsunami hazard. The difficulties arising here are evident: the complexity of coastal zone morphology and the variety of underlying surfaces changing due to their interaction with the water flows caused by Tsunamis,the possibility of waves breaking and competition of nonlinear and dispersion effects. In order to work out the problem this paper reports a numerical simulation of Tsunami propagation with two main components. The first component concern with Tsunami propagation using the *Korteweg and de Vries* (KdV) equation to obtain the travel time and maximum amplitude of the waves in deep water. In the second component we consider the approach of the waves to the shallow water, near the coast, using a Nonlinear water wave theory on a sloping beach.

MECHANISMS OF MEAN HELICITY GENERATION AND ITS ROLE IN CRISIS ATMOSPHERIC SITUATIONS

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We have considered mechanisms of mean helicity generation in rotating systems or in the presence of an external magnetic field. It is shown that at non-zero helicity density (even if the initial mean helicity is zero), mean helicity is generated in the presence of rotation or a uniform magnetic field. The effect may be essentially enhanced by the presence of mean velocity shear or stratification in the system. On the basis of the theory of helical cascade, helical predictors of typhoon generation in equatorial latitudes are discussed.

SCIENTIFIC PROBLEMS OF THE SPACE PROJECT "PRECURSOR"

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The main scientific tasks of the project "Precursor" suggested to perform in the frame of russian segment of international space station "Alfa" are discussed. This project is devoted to study both theoretically and experimentally the influence of solar-terrestrial relationships on the atmospheric turbulence self-organization by help to measure and to analyse the hydrodynamical and electromagnetic fluctuations related to large-scale crisis processes like typhoons. The theoretical problems concerning to project "Precursor" purpose are formulated and argumented. They include the investigation of external triggers influence on the atmospheric chaos structure and self-organization processes, the models and estimations of electromagnetic indicators initiated by large-scale vortices, the studiyng of correlations between X-rays fluxes measured at the satellite heights and typhoons, the modern techniques for experimental data processing and so on. The brief description of experimental equipment suggested to dispose at the scientific module of ISS "Alfa" and including the radiometric complex and X-ray spectrometer is done.

ESTIMATION OF HELICITY PARAMETERS IN WIND SPECTRA AND IN LABORATORY EXPERIMENTS

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The analysis of wind spectra shows that there exist several adjacent ranges of spectral slopes -5/3 and -7/3. It is well-known that such spectral slopes are determined, respectively, by the energy and helicity transfer rates. When simulating atmospheric turbulence in the laboratory magnetohydrodynamic experiments, we have also obtained helical turbulence spectra with such slopes. In the latter case, two adjacent ranges are also observed. Such a multiplicity of wind spectra ranges points to the existence of various sources of both helicity and energy generation in the atmosphere operating over different scales. On the contrary, a laboratory spectrum is generated under simpler conditions under the action of a single source.
Estimations of helicity parameters determined in different spectral ranges are close to the estimations of such helicity sources as the Earth's rotation and thermals for the troposphere and atmospheric boundary layer. The analysis performed makes it possible to identify factors determining wind field generation.

INTERMITTENCY FOR PASSIVE SCALAR ADVECTION

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The Kraichnan model for passive scalar advection is formulated in terms of Lagrangian tracer dynamics. The n–points equal–time correlation functions are thus associated to the evolution of $n-1$ tracer particle configurations. The zero–diffusivity limit is shown to correspond to purely advective dynamics, supplemented by a point–splitting procedure for coinciding points. In this formulation the intermittency of the scalar field arises from the dependence of the particle dynamics on the geometry defined by their positions. Such effects do appear when more than one particle is effectively involved in the dynamics, i.e. starting from the third–order correlations. The anomalous scaling of the structure functions is in particular associated to the persistence of spatial structures and the slowing down of particle separation. The Lagrangian formulation is exploited numerically by Monte–Carlo simulations of particle trajectories in the stochastic velocity field.

ON CELLS MERGING RESULTING TO A LARGE EDDY FORMING

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It is known that a tropical depression deepening can results to a typhoon forming. Due to the helical mechanism of a typhoon creation this process looks like the following. A large vortice is developing through small-scale cells merging providing the fluxes both the energy and the helicity to large scales. In the paper some experimental data a tropical depression deepening and the atmospheric turbulence modification are given and a theoretical model corresponding to them is described. The simplest model showing cells merging during large-scale perturbation growing and directed to visualise this process in terms of a streamline functions is demonstrated. It allows to study the temporal dynamics of streamlines joining on the plane projection during the large-scale motion generation.

UNCHARGED PARTICLE ACCELERATION AND CRITICAL IONIZATION FLOW BY ELECTRIC RECONNECTION AND THEIR APPLICATIONS

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A point-like uncharged particle in motion is usually not affected by electric forces but only by gravitational forces, since it is so tiny that the so-called 'test-particle approach' is feasible. The situation is drastically changed, however, when a dust particle is invading an electric cusp. Then some of adjacent electric field lines in the opposite direction tend to merge toward the particle, inducing or polarizing tiny quadrupole-like charges and producing large local electric fields on its surface, thus electric forces being exerted on the grain. Now subsequent processes are divided into two cases, depending on whether the local electric fields on the grain surface are below or beyond the breakdown threshold of the background gas (or vacuum). For the former case, some of the electrostatic energy tend to be converted into the kinetic energy of the dust particle, leading to its rapid acceleration. For the other case, local surface discharge may take place due to sufficiently high local electric fields, forming a plasma layer around the dust or object and producing critical ionization flow in the form of streamer and leader followed by eventual main discharge, thus some of the electrostatic energy being converted into ionization and flow energy. Applications to some natural hazards are given, including dust-aerosol absorption by thunderclouds and/or ionosphere, pre-earthquake ionospheric effects such as emanation of dust-aerosol particles under the piezoelectric field in the crust, a variety of electromagnetic and plasma anomaly in the atmosphere and ionosphere [Pulinets et al.,1994], Chondrule production in meteorites and so on.

VORTICITY GENESIS IN THE MOIST ATMOSPHERE

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Modification of turbulent dynamo model is constructed which takes into account the inverse damping action of generated large-scale vorticity on small-scale helical turbulence. The model describes a quasi-stationary regime with parameters being determined independently from energy balance considerations under assumption that small-scale turbulence has the moist-convective origin. Intercomparison of both fluid dynamical and thermodynamical approaches enables to estimate helical turbulence parameters that provide the given dynamo-effect. As an illustration, a case of initial tornado-like vortex formation, which takes place in the foot of a rotating storm, is considered.

GENERATION OF STRUCTURES IN GEOPHYSICAL AND GEO-LIKE MEDIA WITHOUT A SYMMETRY CENTER

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Rotation, inhomogeneity, helical motions of various scales, a large amount of biological mass (so called biotes) and organic compounds result in that the geophysical medium should be modeled as a system without a symmetry center. Such a system is characterized by a tendency to structurization in various scales, and the present paper deals with the study of some of its properties.
We analyze electric currents, mass and heat flows arising under exposure to light and further generation of magnetic, electrical and hydrodynamic structures. By way of example, we consider such phenomena as a result of solar-terrestrial bonds.
We examine the effect of chiral electrodynamic fields on the processes of self-organization in hydrodynamic media. Different reasons of the phenomenon of chirality in continuous media are compared, and a competing role of electromagnetic and hydrodynamic chirality is discussed.
On the basis of the photogalvanic effect, taking into account the helicity of vector fields and other related chiral properties, we analyze diagnostic signs of the generation of large-scale geophysical processes.

DETERMINISTIC DESCRIPTION OF A PHASE TRANSITION IN A MEDIUM, OF INTERACTING WAVES

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We start by describing the stability behaviour of an ensemble of identical resonators generating stationary interacting waves taking two precise (non dispersive) values for their phases. Such study offers a useful introduction to the understanding of the general case in which the phases may take any values. It is obvious that by means of a feed-back effect, the interaction among the waves ("via" their resonators) will modify the distribution of the phases in the course of time, and the determination of the equations providing that evolution is the main result of the present paper. The essential tool in this work is a generalisation of a theorem due to Rayleigh for the equation governing the probability distribution of the amplitude and phase of a superposition of a great number of identical waves with "a priori" equal (random) phases (It is the heat equation). The corresponding result for any (non random) distribution of the phases, given in this paper, leads to a bifurcation and a two-fold solution, employed throuhgout this paper. The final results give for the time evolution of the phase distribution of the interacting waves a non linear equation with two different possible structures, one of them describing a phenomenon of a much higher intensity (a phase transition or a catastrophe), the transition between them taking place for a certain precise condition for the initial values.

Vortical Structures in Stratified Turbulent Flows

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The vertical and horizontal structure of stratified turbulent flows is investigated in e series of experiments where oscillating grid and jets or air bubbles are used to stir a initially sharp density interface separating two homogeneous layers.

The collapsing turbulent patches show a characteristic shape of vertically conected disks. If the local Richardson number at the interface is high, then horizontal vorticity is converted into vertical vorticity, leading to a distribution of plane vortices. If the initial density structure shows several layers, the disk shaped vortices interact with each other via two main mechanisms, by means of the local shear produced by the collapsing patches or by means of the internal wave field.

Several experimental techniques, such as LIF, shadowgraphs and Particle tracking are used to characterize the vertical size and the horizontal structure of the mixing patches. The vortical mixing patches produce a trapping effect on pollutants or biological activity in the Ocean , measurements of the eddy diffusivity show a marked dependence on the trapping by these pancake shaped coherent structures.

NP4

MULTIFRACTAL STRUCTURE OF THE AIR TRANSMITTENCY SMALL SCALE FLUCTUATIONS

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The fluctuations of air tranmittency over small time scales (20-500 s), in presence and absence of fog, are analysed from different points of view: Fourier and wavelet transform, multiscaling exponents, multifractal spectrum, structure function. All results indicate a multifractal structure associated with intermittency and whose characteristics do not seem to change with the level of visibility; the origin of this multifractality, whether statistical or dynamical, cannot however be established with certainty.

TOWARDS EARLY WARNING: ARE SELF-ORGANISED CRITICAL SYSTEMS PREDICTABLE?

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It is sometimes stated that self-organised critical phenomena are much more "unpredictable" than, for instance, chaotic phenomena. This conjecture is investigated within the framework of multi-model ensemble forecasting. Both deterministic and stochastic models are considered. The aim is to provide reliable probabilistic information of the likelihood of extreme events over a given period, even in the case that the model dynamics are deterministic. The most promising approach appears to be melding of models which consider a variety of time scales, each of which may have a different model structure.

NP4 Nonlinear waves, coherent structures and natural hazards

03 Shallow water experiments as models of geophysical and astrophysical flows

Convener: Sommeria, J.
Co-Convener: Nezlin, M.V.

Sponsorship: INTAS

SPOTTED DISKS

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We study the formation of coherent vortices on barotropic incompressible Keplerian disk, in both the pure hydrodynamic and the MHD cases. We show that strong anticyclonic vortices can form on Keplerian disks. This fact may have interesting consequences on the process of planet formation in the early solar nebula.

A LABORATORY STUDY ON THE STRUCTURE AND DYNAMICS OF BAROCLINIC VORTICES ON A POLAR β-PLANE.

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Results are presented from a set of experiments performed in an internally heated, rotating cylinder of fluid, in which a polar β-plane has been simulated by the inclusion of oppositely sloping endwalls. The boundaries are arranged so that the fluid depth (D) can either increase with radius ($\partial D/\partial r > 0$) or decrease with radius ($\partial D/\partial r < 0$). Stable eddy features are observed over a wide range of rotation rates (Ω) in both endwall arrangements. The regular wave regime of the $\partial D/\partial r > 0$ endwall experiments consists of modes with azimuthal wavenumbers $m = 1$ to 5. Only the mode $m = 1$ is seen in the regular wave regime of the $\partial D/\partial r < 0$ endwall experiments. The regular eddies seen in the $\partial D/\partial r > 0$ ($\partial D/\partial r < 0$) endwall experiments are found to be 'vertically trapped' close to the bottom (top) boundary, and are seen to reduce their radial scale as the magnitude of the simulated β-effect increases. At high Ω the eddy kinetic energy appears to be trapped close to the Rhines scale $L_\beta = \pi\sqrt{2U/\beta}$ in the $\partial D/\partial r > 0$ end wall experiments, although there is little evidence for an inertial range characterising the inverse energy cascade required by the Rhines argument. In the $\partial D/\partial r < 0$ endwall experiments, however, there is evidence for an inverse energy cascade (with a slope of approximately $\kappa^{-\frac{5}{3}}$) to the smallest wavenumbers that is not blocked by the simulated β-effect. Such a result is consistent with the observation that even at the highest Ω the flow retains a large $m = 1$ component in the $\partial D/\partial r > 0$ endwall experiments.

ON THE MECHANISM OF THE ROSSBY VORTEX MERIDIONAL DRIFT

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The following mechanism for the Rossby vortex meridional drift has been proposed: 1. Under the action of dispersion and the KdV nonlinearity, the Rossby vortex drifting along the system parallel (i.e. azimuthally) suffers the azimuthal deformation, and the maximum of its elevation or depression on the shallow water free surface is shifted in the azimuthal direction. 2. According to the Ertel theorem, the azimuthal vorticity gradient arises in the vortex. 3. That gradient, in principle, acts in the same gyroscopic manner by which the meridional vorticity gradient produced by the meridional gradient in the shallow water depth (or in the Coriolis parameter) causes the azimuthal Rossby vortex drift (and produces the Rossby waves). Analogously, the azimuthal vorticity gradient causes the meridional Rossby vortex drift. 4. Dispersion and the KdV nonlinearity cause the meridional vortex drift either in the same direction (in case of a cyclone drifting westwards and anticyclone drifting eastwards) or in the opposite directions (in case of an anticyclone drifting westwards or a cyclone drifting eastwards). In the second case, at definite conditions, mutual compensation of dispersive and nonlinear effects may occure. It leads to formation of the Rossby soliton propagating exactly along the system parallel. 5. Which effect dominates in general case, depends on the vortex amplitude and size, as well as on the system geometry. The concept mentioned is in a good agreement with the experiment (see M.Nezlin at al, this Session) and the natural observations.

LARGE-SCALE VORTICES: STABILITY AND DEPARTURE FROM GEOSTROPHY

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Numerous isolated vortices observed in nature, especially in the oceans, have characteristic length scale larger than the deformation radius and finite Rossby number. We present her a study on the stability of analogous large-scale vortices in a rotating shallow-water experiment [1]. The paraboloidal geometry used allows an adequate modeling of the f-plane case. A data acquisition technique using light absorption ensure precise measurements of the free surface elevation. In addition a PIV technique gives an independent measurement of the velocity field. The influence of the velocity profile, the size and the ageostrohic effects on the stable or unstable evolution of initially isolated vortices will be confronted to numerical investigations and theoretical predictions.

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Interaction of zonal flow with topography. Laboratory and numerical simulations

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Laboratory and numerical simulations of the interaction between a zonal flow and topography have been performed. The zonal flow was created by the source and sink method in a rotating annulus with a sloping bottom. The meridional structure of the flow was kept by a special distribution of sinks near the internal side wall of the annulus. The topography was taken in the form of one or two mountains passing across the channel. Four main vortex regimes were observed: (1) steady motion, (2) oscillatory motion, (3) the intermittent regime with quasi-periodic vortex breakdown, (4) the intermittent regime with incomplete vortex breakdown. The most fascinating is regime 3. In this regime, one observes periodic formation of vortex system downstream the mountain, and its growth followed by breakdown. The zonal flow changes noticeably at the stage of mature vortices. Immediately after the breakdown a chaotic pattern of smaller vortex fragments is formed, whereas the zonal flow restores to its initial profile. This sequence of events is repeated with a period on the order of 20-40 cycles. Numerical simulations are performed by spectral method (the Fourier series in the zonal direction and the Chebyshev polynomials along the radius) in the framework of Q2D approximation. They qualitatively reproduce the observed vortex dynamics.

Transverse structure of Q2D geophysical and magnetodynamical flows

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The detailed comparison of transverse structure of Q2D geophysical and MHD shear flows is carried out on the basis of the classical approach developed by Stewartson, Shercliff and others. The sewing conditions of Ekman layers in the vicinities of horizontal wall together with Proudman-Stewartson layers in vertical neighborhood of the velocity shear are formulated. The physical mechanisms responsible for smoothing of horizontal velocity shears and bottom friction laws are discussed. The resultant 2D vorticity equation with a Rayleigh friction term is known to give description of Q2D vortex geophysical and MHD flows consistent with 3D theory provided that correct choice of the bottom friction coefficient has been done. The coefficient depends on the physical parameters of system; explicit formulae are derived to calculate its values. The results deserve attention for the construction of laboratory set-ups and numerical schemes on simulation of developed Q2D flows including constrained Q2D turbulence.

NUMERICAL SIMULATION OF INSTABILITY IN ROTATING SHEAR LAYER IN GALACTIC DISKS AND SHALLOW WATER EXPERIMENTS

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We present the results of 2D and 3D numerical study of the rotating thin layer dynamics with an angular velocity kink. The linear and non-linear stages of instability are investigated. A comparative analysis of two different models, the shallow water model and the model of compressible gaseous astrophysical disks, is given.

ND4

ASSIMILATION BY PERIODIC UPDATING IN A SIMPLE HAMILTONIAN SYSTEM AND APPLICATION TO A SIMPLIFED SHALLOW WATER MODEL

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A simple Hamiltonian system is used to show that convergence of assimilation by sequential updating is a decreasing function of the updating time interval Δt up to a certain turnover point Δt_o where the process reverses. The key point, using a second order Taylor expansion of the system resolvent, is that the convergence is basically of order $O(\Delta t^2)$ for small Δt.
Application to a 1D nonlinear shallow water model shows that when the zonal or meridional wind are updated, the maximum convergence is obtained when the observations are inserted approximately every 4 hours. A low order simplified dynamical system derived from the shallow water model is used to show that this optimum time interval Δt_o varies approximately as $\frac{\sqrt{2}}{2\Omega|\sin\varphi}$ to accuracy $O(\Delta t^3)$. Attention is also focussed on the use of the linearized model and we conjecture that when the (quasi-) stationary basic state of a geophysical model is close to the climatology, then the linearized version can be used to diagnose the turnover point.

QUASI-TWO-DIMENSIONAL MODELLING OF THIN ASTROPHYSICAL GASEOUS DISKS

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We discuss at once the tight analogy and the fundamental difference between the shallow water model for incompressible fluid and the quasi-2D models for compressible thin gaseous disks in astrophysics. We give a critical review of current thin disk approximations in astrophysics and their crucial shortcomings. We present our new self-consistent method for computing quasi-2D dynamics of thin disks free from the mentioned drawbacks. The important novel feature of the present algorithm is proper taking into account the vertical motions, the multimodal nature of oscilations in disk and an arbitrary, non-barotropoic equation of state of gas. The influence of excited vertical motions on global quasi-2D dynamics is demonstrated by some examples based upon this model.

LARGE SCALE DYNAMICS OF FREELY DECAYING SHALLOW-WATER TURBULENCE ON A SPHERE

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We have performed long (several hundreds planetary rotations), very high resolution (up to an equivalent T700 spectral truncation), simulations of freely decaying shallow water turbulence on a rotating sphere, spanning a wide range of values of Rossby and Froude numbers.
The numerical method used in these simulations is the "Cubed Sphere", a new grid point, composite mesh, method for solving PDE's in spherical geometry, which allows to obtain the same accuracy as the spectral transform method, with substantial savings in computing time.
In this work, we focus our attention on the spontaneous formation of zonal jets and on the final, steady-state, zonally averaged profiles. We investigate the influence of spatial resolution and initial conditions on the number, intensity and latitudinal extent of the zonal jets. At sufficiently high rotation speeds, a strong equatorial jet is formed, in the direction opposite to that of planetary rotation. The mechanism of formation of this jet is investigated.
Finally, we find that, at small Rossby numbers, the quasi-steady state reached in the final stages of the simulations is characterized by a wind field satisfying a zonally averaged geostrophic relation, even though the velocity can deviate substantially from local geostrophic balance.

A THERMAL WIND IN PANCAKE VORTICES IN A STABLY STRATIFIED FLOW

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In rapidly rotating flows, vortices form Taylor columns aligned with the vertical rotation axis z. When the flow is thermally stratified the Taylor-Proudman theorem is modified so that $\partial \mathbf{v}/\partial z$ is no longer zero but proportional to the horizontal temperature gradient $\nabla_H T$. This is the Thermal Wind Equation (TWE). With a proper $\nabla_H T$ pancake-shaped rather than columnar vortices form. Planetary vortices are pancake-like. An isothermal pancake vortex will not satisfy the TWE, and creates a secondary flow similar to Ekman pumping. This flow creates a $\nabla_H T$ in accord with the TWE. However, the vortex decays slowly, and for small Prandtl number, with the thermal rather than viscous, timescale: thermal conductivity acts to destroy $\nabla_H T$, but it is maintained by the secondary flow (which is forced by the imbalance in the TWE if $\nabla_H T$ decays). Thus the thermal timescale regulates the secondary flow. Kinetic energy flows from the primary vortex into the secondary flow which transforms it to potential energy (as it advects heat against the stable stratification). The potential energy (stored as cold above hot fluid) is then thermally dissipated.

MERIDIONAL DRIFT OF THE ROSSBY VORTICES

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The meridional drift velocities of the Rossby vortices on the shallow water rotating together with a parabolic vessel have been measured. The shallow water depth gradient was regulated by means of variation of the paraboloid rotation period. The results obtained are the following. (1). Cyclones and anticyclones drift along the meridian in mutually opposite directions. (2). In general, the meridional drift velocity is only an order of magnitude less than the azimuthal drift velocity (along the parallel). (3). The meridional drift velocity equals zero at the vessel rotation period, at which the Rossby velocity (of linear waves) changes the propagation direction. Therewith, the nonlinear cyclones propagate eastwards, the nonlinear anticyclones, westwards, and the life time of the vortices passes through a maximum. (4). The absence of the meridional drift is the necessary condition for the Rossby soliton (a cyclone drifting eastwards and anticyclone drifting westwards). (5).The following mechanism for the vortex meridional drift has been suggested. Under the action of dispersion and nonlinearity, the vortex drifting in the azimuthal direction suffers an azimuthal deformation which produces the azimuthal gradient in the hydrostatic pressure. The latter causes the meridional vortex drift by the same gyroscopic mechanism, by which the stationary meridional gradient in the shallow water pressure causes the azimuthal Rossby vortex drift (and produces the Rossby waves). The conception mentioned is in a good agreement with the experimental data.

GENERATION OF VORTEX PATTERNS AND SPIRAL WAVES IN A SHALLOW WATER ANNULAR SHEAR

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We produce an annular shear flow in a shallow water layer entrained by a bottom plate in differential rotation. The inner part is rotating while the outer part is at rest, generating an intense shear along the contact line. The inner part has a parabolic shape so that the layer thickness remains constant in average. We study the development of shear instability and its organization into a vortex ring and the emission of spiral surface waves (equivalent to sound waves in a 2D system). This problem has been already studied experimentally by Nezlin and Snezkhin, but the new contribution is a quantitative analysis of the emmitted spiral waves.
These are found in good agreement with a model of wave emission by the rotating ring of vortices, using a the perturbative method of Lighthill. We find that the vortex ring always organizes such that the Mach number never exceeds unity, avoiding shock waves. The transport of angular momentum by the spiral waves is also discussed.

MODELLING OF THE MECHANISM OF OCEAN SURFACE COOLING BY UNDERWATER EARTHQUAKE.

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The appearance of the large-scale (~500 km) cold sea surface temperature anomalies were discovered in the epicentre region of the strong underwater earthquakes near Bougenville Isl. in May, 1996. The estimations carried out from the energetic point of view show that the mechanism of the SST anomaly origin was certainly connected with an export of cold lower water layers to the ocean surface as a result of turbulent mixing or vertical nonlinear currents generated by seismic bottom motions. For the sake of revealing the mechanism laboratory experiments with the system "stratified fluid on the oscillating bottom" were fulfilled. In particular it was shown that there is a dynamic mode in the system when the vertical eddy diffusion coefficient grows dramatically (by three orders). It gives us grounds to state that one of the possible mechanisms of the SST anomaly origin in the underwater earthquake epicentre region occurs due to an effective transfer of energy from the moving bottom to the ocean turbulence.

FLOW PAST ISOLATED TOPOGRAPHY: A COMPARISON BETWEEN CONTINUOUSLY STRATIFIED AND SHALLOW-WATER DYNAMICS

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Shallow-water and continuously stratified flows past isolated topography are characterized by a wide range of surprinsingly similar flow features including the transition into a dissipative regime, the formation of lee vortices, and the occurrence of vortex shedding. A comparison between these two flow systems is undertaken using high-resolution numerical simulations. Both flow systems show two distinct nonlinear flow regimes. These are associated, respectively, with the occurrence of a hydraulic jump (gravity wave breaking), or flow splitting and flow separation within the shallow fluid layer (on the lowermost isentropic surfaces).
The analysis of the results using potential vorticity dynamics suggests that the qualitative similarities between the two flow systems rely upon the existence of (i) a potential vorticity relationship, and (ii) a generalized form of the Bernoulli theorem. The latter equates gradients of the Bernoulli function on density surfaces with either advective or dissipative fluxes of potential vorticity, and thereby provides a link between dissipation and associated dynamical effects such as the formation of lee vortices.

LABORATORY MOSELLING OF INTERNAL WAVES GENERATION BY DRIFTING ICEBERG

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Results of laboratory investigation on internal waves generation by a vertical cylinder are presented. Experiments were performed in thermally stratified tank in IAP RAS with overall dimensions $L * B * H = 18 * 4 * 2\ m^3$ with the horizontally homogeneous thermocline–type stratification created in the fresh water, so providing a scale model of the seasonal ocean thermocline.
The cylinder crossed the free surface and had various depth T relatively to the thermocline's level h_0 ($T/h_0 = 0.5 - 1.5$). The velocity range was similar to natural iceberg drifting velocity. The mode structure of the IW field, the phase picture and the IW amplitudes versus the cylinder's draught and velocity are obtained. Both dispersive and nonlinear IW effects were observed.
This work was supported by the RFBR grants no. 96-05-64457, no. 96-05-64476 and INTAS grant no. 94-4057.

SHALLOW WATER EXPERIMENTS WITH A SPHERICAL ICOSAHEDRON-BASED MULTIGRID MODEL

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Results of numerical simulations will be reported pertaining to a variety of instances of barotropic and shallow water dynamics on the surface of the sphere. These have been obtained with a new grid-point based methodology which makes use of a nested mesh structure deriving from successive dyadic refinements of the spherical icosahedron. In combination with multigrid methods, spatial discretization schemes of this type can improve algorithmic complexity to $\mathcal{O}(n)$ from the $\mathcal{O}(n^2)$ of pseudo-spectral models (n being the number of degrees of freedom). We have implemented models based upon the basic framework which integrate the vorticity-streamfunction formulation of the barotropic system and the velocity-height formulations of both the barotropic and the shallow water systems. The results to be described will include cases from the standard test set for shallow water models on the sphere (Williamson, *et al*, 1992), as well as reproductions of a previous simulation by Juckes and McIntyre (1987) of the erosion of the stratospheric polar vortex by an impinging Rossby wave. We will also discuss new work relating to the dynamics of zonal flows and vortical structures in the stratospheres of the gas giant planets. The influence of varying height fields on piecewise homogenized "staircases" of barotropic PV will be considered.

PHYSICAL MECHANISMS OF AN INTENSE VORTEX MOTION

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Intense vortex motion resulted from its nonlinear interaction with a large-scale flow with weak gradient of the potential vorticity is analyzed. Physical mechanisms of a vortex center motion relative the large-scale flow are described by decomposing the vortex circulation into symmetric and asymmetric components. The special structure of symmetric vortices drifting steadily due to the Rossby wave mechanism is emphasized. All other vortices include asymmetric circulation that represents another physical mechanism for additional stationary or nonstationary vortex motion. Relative contributions of both mechanisms are estimated for barotropic and baroclinic vortices. Results are compared with geophysical observations, laboratory modeling and numerical simulations.

POSSIBLE VERIFICATION OF THE DEFORMATIONAL LONG-WAVE INSTABILITY EFFECT

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The deformation of the upper surface of the rotating fluid layer heated from below can be the reason for appearance of horizontal temperature gradients. These temperature gradients can give rise to baroclinic component of the flow which is, in fact, the thermal wind. If the upper surface is not sustained at constant temperature the initial disturbances of the upper surface tend to zero because flows are damped out due to viscosity. But in opposite case a new effect can appear, i.e. the increase of the deformation amplitude. This effect was called in our previous paper as the deformational long-wave instability. The necessary conditions for this instability to be realized, besides the heating from below, are the small thickness of the layer in respect to the horizontal scale of the flows and rather rapid rotation. Here we discuss the possibility of verifying the validity of the theory of the deformational long-wave instability by shallow water experiments.

A SPECTRAL DOMAIN DECOMPOSITION METHOD TO RESOLVE A STRONG LOCALIZED SHEAR LAYER

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Kelvin-Helmholtz and centrifugal instabities coexist in a strong shear layer in rotation if the angular momentum decreases outwards. We have already studied them numerically with a 2D barotropic compressible pseudo-spectral code and found a qualitative agreement with shallow water experiments. But for quantitative comparisons, the shear width is expected to be tightened. To correctly resolve the shear with Chebyshev spectral method in the radial direction, the number of points (or frequencies) can be increased, but not indefinitely. Moreover, the better accuracy is at the boundaries. As the shear is localized around the middle of the radial annulus, we have chosen to join 2 Chebyshev domains at this position. We will link the 2 domains with the characteristics method by traiting, at the interface, only the waves travelling radially, due to the advection terms of the full Naviers-Stokes equations. Some results (most instable frequency and its linear growth rate) and comparisons with shallow water experiments (number of stationnary vortices, drift velocity) will be showed at the same convective Mach number and ratio of the shear radius over the shear width.

Particle tracing in a circular shear layer

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The trajectories of particles in the vortical structures generated by a shear layer are investigated. In the experiments, a small number of floating tracer particles is released in the shear region, and their paths are extracted from a video recording made in the rotating system. Due to a slight unsteadiness in the flow field, a particle can move between qualitatively different orbits, and one can observe trapping and detrapping of the particle by a vortex. A determination of very long particle traces and their chaotic properties is the subject of present investigation; moreover, studies of the effect of different sizes of particles will be carried out. In order to study particle trajectories in a shear layer numerically, the numerical code has been extended with a module that is able to follow individual particles with spectral accuracy. Apart from tracing a single particle over a long time, the numerical method is suited for studying the dispersion of a large number of particles. In general, one finds that particles that are released close to a vortex centre remain trapped indefinitely, but that particles released at the edge of a vortex show an irregular motion corresponding to trapping and detrapping.

Influence of the beta effect on shear-flow instability

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The influence of the beta effect on the instability of a forced, circular shear layer in a rotating layer of water is studied experimentally and numerically. The experiments are carried out in a rotating parabolic vessel with a differentially rotating inner section. Above a critical value of the inner rotation, the shear layer becomes unstable, and evolves into a number of equally signed columnar vortices. A topographic beta effect is introduced by a faster (beta>0) or a slower (beta<0) background rotation. In geophysical terms, the case beta>0 corresponds with dynamics around the North or South pole. Thus, using the terminology of the northern hemisphere, the ‹north› corresponds to shallow, and ‹south› to deep. Both the number of vortices and the steadiness of the final vortex pattern appear to be influenced by the beta effect. In particular, the vortex chain becomes less susceptible to instability if the inner section rotates in the eastward direction, and tends to become unsteady in the opposite case. The angular velocity of the vortices around the centre of the vessel appears to be much lower than the average of the inner disk and the outer part of the vessel, an effect that can be explained in terms of nonlinear advection of vorticity by the vortex chain. The experiments are supported by numerical simulations based on the spectral solution of the quasi-geostrophic equation in a geometry similar to the experimental situation.

SE27 Mechanics of tectonic and volcanic earthquakes (joint with NP)

Convener: Sileny, J.
Co-Convener: Panza, G.F.

AUTOMIZED MOMENT TENSOR INVERSION OF FLUID-INDUCED MICRO-SEISMICITY IN SALT

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Amplitude spectra of body-wave phases are used to estimate moment tensors of swarm-events in an automized procedure. For this, single and multiple event methods have been extended to amplitude spectra data, and to one component sensors with known orientation. The resulting nonlinear inversion problem is, after a Taylor series expansion, iteratively solved beginning with an initial source model. To avoid convergence to a local minimum we use a grid search over initial fault orientations on the focal spheres and choose, after a number of fixed iterations, the solution having the least residuals between observed and predicted amplitude spectra. To further stabilize the inversion we optionally use a general dislocation source constraint. The methods are tested on synthetic waveform data and on fluid-induced micro-cracks in salt. There, about 100 events span a volume of $\approx 1m^3$ surroundig a macro tension-crack with a radius of $\approx 0.5m$. The waveforms have been recorded with 8 piezo-sensors in 3-10 m distance. Preliminary results indicate tension source components. We will discuss the estimated source mechanisms in terms of fracture-mechanical processes during the development of a tension crack.

SEISMIC MOMENT TENSOR OF WEAK CRUSTAL EARTHQUAKES OF VRANCEA (ROMANIA) RETRIEVED BY WAVEFORM INVERSION

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The inversion of high-frequency seismograms is performed to retrieve the seismic moment tensor for weak crustal earthquakes ($2.9 \leq M_L \leq 3.6$) of Vrancea region (Romania). The source is described by the full moment tensor, having both volumetric component and deviatoric part. Synthetic seismograms are computed by the modal summation method, using the point source approximation, for horizontally layered anelastic media. The digital waveforms recorded by the Romanian local network (velocity records, vertical component, with sampling rate of 50 samples/sec) are used. The method performs dynamic relocation of the hypocentre and a simple optimization of the structural model simultaneously with the determination of the source mechanism.

SEISMIC MODELING OF EXPLOSION EARTHQUAKES OF MT. ARENAL VOLCANO, COSTA RICA

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The seismic modeling of explosion earthquakes was made for earthquakes related to the 1991 eruptive activity of the Mt. Arenal volcano, Costa Rica, during 8 to 16 of April and 7 to 18 July. There were investigated 20 digital short-period 3-component seismic records. The simultaneous recording of sound waves had allowed to control the nature of seismic events. The synthetics were calculated for vertical force that represented a counter force of eruption (Nishimura, 1995). There is shown that the multiple forces can better model the explosion earthquake source than the single force. The best coincidence of the observed records and synthetics was obtained for a sequence of 4 or 5 vertical forces which were included consistently with an interval of 0.5 sec. The calculated counter forces of explosions were compared with the published worldwide data.

AFTERSHOCK SERIES OF EVENT FEBRUARY 18, 1996: AN INTERPRETATION IN TERMS OF SELF-ORGANIZED CRITICALITY

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An aftershock interevent time series, initiated on February 18, 1996, in the eastern Pyrenees was analyzed. The original time series does not fit Omori's law, probably because of sudden changes in the rate of occurrence, interpreted as an increase in the production rate. When the recorded interevent time series is classified in terms of leading aftershocks (those that satisfy a relaxation process) and cascades (those occurred at a nearly constant rate), the new time series of the leading aftershocks fits Omori's law quite well, with $p = 0.94$. Interpreted in terms of Dietrich's model, the series of leading aftershocks correctly predicts a return time for the main shock of the order of 50 years. To interpret the series of cascades, a minimalist, self-organized critical model was used. Although it is very simple, the model correctly reproduces the two-level structure in the observed time series, that is, the sequence of leading aftershocks and a cascade sequence emerging from each aftershock. This model may be given physical justification in terms of the *Cochard and Madariaga* [1996] nucleation model.

ON THE RESOLUTION OF THE ISOTROPIC COMPONENT IN MOMENT TENSOR INVERSIONS

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If it is in theory possible to solve a full moment tensor from inversion of a few seismograms, the isotropic component is often set to zero in practice in order to stabilize the inversion. We investigate under which practical conditions the determination of the isotropic component is mathematically and physically reliable. First, we examine the question from a physical point of view and show that the classical interpretation of a full moment tensor for tectonic events implies rheological constraints that are not always realistic. We propose an extended physical model which includes tectonic and non-tectonic volumetric variations. Then we use the tools of inverse theory to infer mathematical constraints on the problem of full moment tensor inversions from teleseismic spectra. In particular, we examine how much of the moment tensor can be solved, in relation with the eigenvalues of the inverse problem. The resolution and the correlation matrices show that, among a choice of possible constraints on the full tensor, a constraint on the isotropic component is most valuable. In addition to the estimation of the tectonic and non-tectonic isotropic components in full moment tensor inversions, we finally propose extensions of the basic linear methods that can lead to particular models in subspaces of interest, such as tectonic models, or decompositions in a double-couple plus a volumetric part. Some applications of our theoretical developments to regional waveform inversions are shown, for the April 1992, Roermond, earthquake.

Earthquake Moment Tensor and Source Location Retrieval Using Three-Component Waveform Data

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The main purpose of this work is to analyse global inversion of waveform data for the moment tensor and source retrieval using three component data from seismic stations. For this purpose we have extended to the SH component of motion the method preposed by Sileny et al. (1992). The main advantage of considering all three components at each recording station is to reduce the number of necessary stations and hence not only the cost of the seismic network, but also the noise introduced by the insufficient knowledge of the physical properties along the source-receiver path.

It is well known, that the source depth is poorly resolved by Love waves, whereas Love waves add information to the moment tensor components. Rayleigh waves includes information of both source depth and earthquake mechanism. The source is assumed to be a point source in space but not in time. The procedure used finds the global solution of moment tensor, source-time function, and source location. Green functions are interpolated between two extreme models of the structure, representative of the considered area. The first step retrieves the source location and the moment rate tensor components as functions of time, and in the second step, these time dependent moment rate tensor components are inverted to obtain an average constant moment tensor and a common source time function. Synthetic

RIFT-ZONE AND OFF-RIFT EARTHQUAKES IN ICELAND

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Most earthquakes in Iceland are associated with the rift zone and the off-rift ocean-ridge discontinuities, the Tjörnes Fracture Zone and the South Iceland Seismic Zone. Earthquakes in the rift zone rarely exceed M6; most are less than M5 and generated by slip on normal faults. Much of the rift-zone seismicity is associated with central volcanoes, both during and between episodes of volcanism and rifting. Most central volcanoes have shallow crustal magma chambers and geothermal fields where small changes in stress concentration or fluid pressure can trigger earthquakes. The largest earthquakes associated with the ocean-ridge discontinuities reach M7-7.5 and are generated by slip on strike-slip faults. These discontinuities are located between overlapping rift-zone segments and concentrate shear stresses during spreading in the adjacent rift segments. Numerical results indicate that simultaneous spreading in subparallel rift-zone segments gives rise to the largest earthquake sequences in Iceland.

ERROR ESTIMATE OF THE MECHANISM BY MONTE CARLO SIMULATION

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Traditional approaches to estimate the error imposed on the retrieval of the mechanism of an earthquake, its rupture history and seismic moment by a noise contamination of waveform data, rely on validity of the assumption that statistical properties of the noise are ruled by a particular distribution law, prevailingly the Gaussian one. Supposing the noise can be described by its standard deviation, its variance is transformed by data kernel of linear or linearized inverse problem into covariance matrix of model parameters describing the seismic source. This approach suffers from two drawbacks: (i) the problem is non-linear; (ii) the distribution of the noise may be non-Gaussian, or may be not known at all.

We introduce the approach avoiding both the shortcomings: the region of all the solutions expected by inverting the noisy data is constructed as a set of solutions of the inverse problem for individual realizations of noisy data. They are generated from a sample of observed noise by Monte Carlo simulation: white noise is convoluted with the observed noise sample yielding a particular realization of the noise which is random but retains the characteristics of the observed sample. This approach allows us to consider even the situations when the noise has different characteristics on individual channels to be inverted.

GEOMECHANICS OF THE EARTH'S CRUST OF THE TRANSCARPATHIANS AND MECHANISMS OF LOCAL EARTHQUAKES ACCORDING TO MACROSEISMIC DATA.

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Among basic features of a geodynamic mode of the Earth's crust of the Ukrainian Transcarpathians are tectonic compression (0,000001 units/year) perpendicular to the Carpathians, small (25 km) thickness of the Earth's crust and strong differentiation between rheological properties of rocks and the depth which is due to higt (60-80 mw/sq.m) heat flow in the mantle. These reasons determine peculiarities of the Earth's crust geomechanics and specific mechanisms of local earthquakes, in particular, sliding of the upper massive "granite" layer about the surface of the "basaltic" layer due to a strongly fractured underlayer with a reduced by 0,2-0,3 km/sec value of velocity Vp present in the lower part of the "granite" layer; this underlayer is attenuated by a thermomechanic mode, cataclasis and thermochemical processes. These peculiarities are represented in macroseismic fields by distinctive muzhroomlike configurations of isoseisms, correspondent displacements of macroseismic epicenters relatively instrumental ones, time delays and spatial migration of aftershocks, as well as other spatial-temporal characteristics of a seismic mode. The Earth's crust general structure, in particular, the surface of a crystalline basement, is also perceptible in macroseismic field characteristics.

LOW FREQUENCY SPECTRAL METHOD FOR FOCAL MECHANISMS OF WEAK EARTHQUAKES IN WESTERN GREECE

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Focal mechanisms are studied for selected weak local tectonic earthquakes of Corinth Gulf (Western Greece). The method is based on complex-valued low-frequency spectra below the corner frequency, along with theoretical Green's function spectra (calculated by the discrete-wavenumber method), which is used to invert for the time-independent components of the seismic moment tensor. No apriori constraints of a pure deviatoric and/or double-couple solution are employed. The restriction to the low frequencies disables study of the source time function, but decreases the undesired sensitivity of the method with respect to the unknown structural details. The records are processed as a whole, without any separation of the individual waves, thereby not requiring any amplitude picking. These features make the method robust enough, applicable to small networks of a few 3-component stations. The results are compared with focal mechanisms determined by other methods. Errors and uncertainties are discussed both on synthetic and real data sets.

TESTING OF THE EMPIRICAL GREEN'S FUNCTION DECONVOLUTION CAPABILITY IN THE SPECIAL CASE OF VRANCEA SUBCRUSTAL EARTHQUAKES

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Vrancea is one of the few singular seismic regions of the world where intermediate-depth earthquakes are permanently generated (around 10 events/month with $M_L > 3$) within an extremely confined focal volume. This particularity makes it like a suitable site for application of EGF technique. The purpose of the paper is to test how well the EGF deconvolution succeeds to constrain the source and to optimize its application to Vrancea earthquakes. Three main events: March 11, 1983 (M = 5.4), April 12, 1983 (M = 5.1) and August 7, 1984 (M = 5.1) located in the lower part of the subducting lithosphere (h ~ 150 km) are considered. A set of 30 events (3.0 < M < 4.4) occurred between 1981 and 1997 are selected as corresponding empirical Green's functions. The relatively large number of available waveforms allow us to test the performance of the EGF technique in retrieving the source time function and source directivity.

ARE THE SOURCE PARAMETERS OF THE VRANCEA (ROMANIA) SUBCRUSTAL EARTHQUAKES DEPTH DEPENDENT?

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Vrancea intermediate-depth seismic zone ($60 < h < 200$ km) is characterized by a well-confined focal volume (the corresponding epicentral area is less than 3000 km^2). Several observations (number and size earthquake distribution on depth, fault-plane solutions) suggest that the seismic regime varies downdip the subducting lithosphere.
The goal of this paper is to outline any trend of depth dependence in the source parameters in case of the Vrancea subcrustal earthquakes. To this purpose, the Empirical Green's Function deconvolution is used on a set of more than 150 events with focal depth covering the entire intermediate-depth range. The major shocks of August 30, 1986 ($M_w = 7.2$), May 30, 1990 ($M_w = 6.9$) and May 31, 1990 ($M_w = 6.3$) are also considered.
Possible trends are tested relative to the random fluctuations. Finally, correlation with seismic cycle modeling for Vrancea region is discussed.

COMPARISON OF OBSERVED SECULAR VARIATION WITH THE CHANGES OF THE IGRF IN GERMANY

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In 1965, 1982 and 1992 repeat measurements of the magnetic field at selected stations have been made in the Federal Republic Germany. From them approximative polynomials for the secular variation were calculated for the intervals 1965 - 1982 and 1982 - 1992 and compared with the IGRF changes:

1. The signs of the changes of the measured regional field and of the IGRF are identical for the linear and for the quadratic terms. The quadratic terms of the regional field changes are about 2.5 times larger than the respective IGRF terms, the linear terms 1.5 times larger. Consequently, the secular variation is included (only) partly in the IGRF.
2. The mean north-south gradient has increased from 1965.0 to 1982.5, afterwards decreased. The east-west gradient and the quadratic terms have retained their signs. The increase of the main field since 1982.5 is much smaller than before.

As the source of the secular variation is suspected in the core of the Earth, core field contributions become visible here which are included in the IGRF only partly. The strong and areally small changes imply that for some substantial processes within the core the time constant is in the order of decades. This indicates similarly fast temperature changes at the core-mantle boundary.

ROBUSTNESS OF POINT SOURCE MOMENT TENSOR RETRIEVAL IN THE ETNA VOLCANIC AREA

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We determine the complete seismic moment tensor of a set of shallow earthquakes in the Etna volcanic area (Italy) using the method developed by Sileny and Panza (1991). This method does not need an initial source model and consists of two steps: linear waveform inversion, from which the moment tensor rate function (MTRF) is retrieved and subsequent factorization of the MTRF to compute the average fault plane solution and the corresponding source time function.
As to investigate volume changes of the source related to movements of magmas and lenticular cracks connected with fluid circulation, we are interested in the temporal evolution of the isotropic and of the deviatoric component, some preliminary tests have been done to estimate the reliability of the obtained solutions. The robustness of the moment tensor solution is investigated for different structural models and for various station distributions. Advantages and limits of the method are throughly discussed.

FOCAL MECHANISM DETERMINATION IN ANISOTROPIC MEDIA: NUMERICAL STUDY

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Properties of seismic waves in anisotropic media and implications to seismic wave inversion for determination of focal mechanism are studied. The study comprises an inversion with P waves only, and with P and S waves together. By numerical modelling we quantify errors induced by using an incorrect structure model. In particular, we concentrate on errors induced by using an isotropic model instead of a true anisotropic one. We evaluate a range of anisotropy for which effects of anisotropy in focal determination are negligible. We discuss limits of applicability of standard inversion techniques for region where weak anisotropy is present, which is a quite common situation in many areas.

CORRELATION OF ANOMALOUSLY HIGH b-VALUES WITH MAGMATIC ACTIVITY

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By mapping the b-value of the frequency-magnitude relationship in three-dimensional grids with node spacing of less than a kilometer, we show that about 80% of the seismically active volumes under volcanoes show normal b-values ($b \leq 1$). The rest is occupied by small volumes ($r \cong 1$ km)of anomalously high b-values ($b > 1.3$). This means that the average earthquake size in the anomalous volumes is clearly smaller than in the normal crust. This can be explained either by greater heterogeneity or lower effective stress in the anomalous volumes. The volumes with anomalously short crack size (high b) correlate with the location of magma chambers at the following volcanoes investigated so far: Mount St. Helens, Mount Spurr, off-Ito volcano and Long Valley caldera. In two locations, pronounced increases of b-values from 0.8 to >1.3 as a function of time with progressing intrusions could be documented in volumes of about 5 km radius. The simplest explanation of this observation is to assume that an increase in pore fluid pressure took place, because the alternative, an increase in fracturing (heterogeneity), should not be a unique occurrence in a volcano that has existed for thousands of years, and the affected volume seems too large. We conclude that detailed mapping of b-values can aid in defining active magma bodies.

SE31 Mechanics and thermalfluid-dynamics of volcanic processes: modelling, observations and laboratory experiments (co-sponsored by NP)

Convener: de Natale, G.
Co-Conveners: Allard, P.; Bonafede, M.

Sponsorship: MARS

SPACE-TIME PATTERNS OF SEISMICITY AND STRESS-STRAIN PARAMETERS AT MT. ETNA, SICILY: VOLCANIC AND TECTONIC IMPLICATIONS

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The local shear-earthquakes recorded at Mount Etna between 1990 and 1996 have been analyzed for hypocenter locations and fault-plane solutions. Related stress and strain parameters were then computed by the Gephart-Forsyth and Kostrov algorithms, respectively. Space-time patterns of seismicity, seismogenic stress and seismic strain over the whole period investigated (which includes two notable eruptive phases in 1991-93 and 1995-96) have been analyzed jointly with ground deformation, gravimetric, and geologic information available. The findings lead us to believe that seismicity located in the upper crust beneath the volcano is mostly associated with east-west magma hydraulic pumping in ca. north-south-oriented uprise structures, and closely relates to inflation phases of the volcano preceding eruptive episodes. It is notheworty that volcano deflation revealed by geodimetric and tilt data during the 1991-1993 major eruption was not accompanied by any significant shear-type shallow earthquake. In the intermediate and lower crust (10-30 Km) beneath the volcano, the regional-scale tectonic compression, related to the Africa-Europe north-south slow convergence, appears to be dominant in terms of stress-strain effects. Finally, some analogies between the results of the present study and the findings of similar investigations performed in other areas are discussed.

TRANSFER STRUCTURES AND VOLCANIC ACTIVITY ALONG THE TYRRHENIAN MARGIN OF CENTRAL ITALY

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The Tyrrhenian margin of the central italian peninsula has been characterized by Plio-Quaternary extension, mainly occurred through NW-SE normal faults, offset by coeval NE-SW normal and oblique transfer faults. A sequence of Plio-Quaternary volcanoes developed along the margin, in correspondence with NE-SW structures, suggesting a systematic relationship. The largest central volcanoes, often showing caldera-like depressions, are related to wide-spaced NE-SW faults. At the intersection among NW-SE and wide-spaced NE-SW systems, extensional stresses focus, thinning the crust and enhancing the rise of magma. Conversely, smaller districts (Amiata, Tolfa, Ceriti, Ernici) only display fissural eruptions, connected to narrow-spaced NE-SW transfer systems. In order to study the relationship between narrow-spaced transfer systems and fissural volcanism, analogue and numerical modelling have been performed. Analogue sand-box models in extensional domains simulated the development of vertical transfer faults linking offset normal faults dipping 60°. Analogue models confirm that NE-SW systems may represent transfer faults of NW-SE normal faults. The mechanical model shows that, due to the least lithostatic load, vertical faults such as transfer faults, need the smallest magmatic pressures to be penetrated. Vertical faults can moreover be penetrated at greater depths, tapping the potentially more primitive magma. The models suggest that the location and the structural setting of volcanoes on the Tyrrhenian margin are related to the presence, spacing and vertical geometry of NE-SW transfer systems.

MODELLING GRAVITY VARIATIONS CONSISTENT WITH GROUND DEFORMATION IN THE CAMPI FLEGREI CALDERA (ITALY)

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The last two episodes at Campi Flegrei (1970-72 and 1982-84), both characterized by significant ground uplift and gravity variations, are studied employing an elastic model with a spherical source of deformation applied to a stratified half-space. The contributions to gravity variations produced by the displacements of the surface, the subsurface layers, the relative volume change and the deformation source at four different stations (Serapeo, Solfatara, Bagnoli and La Pietra) were computed. These contributions and the measured (at the same stations) gravity residuals were compared, to draw inferences on the physical processes responsible for the deformation. Results show that an inflation at constant mass would produce gravity residuals much lower than observed, so that this deformation mechanism can be safely ruled out. An inflation source at constant density would predict gravity residuals compatible with observations, even if the resolving power of gravity data prevents accurate assessment of the density of the emplaced material. If the geothermal system is assumed to be responsible of the observed anomalies, computed residuals become compatible with measured values, due to the input of new fluid mass. The comparison between two stratified models reveals that gravity anomalies are not significantly sensitive to the detailed knowledge of the density stratification.

TEMPORAL VARIATIONS IN GROUNDWATERS RADON CONTENT AND GEOPHYSICAL ACTIVITY IN CAMPI FLEGREI (SOUTHERN ITALY)

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The Campi Flegrei caldera is an active volcanic complex, located west of Naples, presently exhibiting slow vertical ground movements known as "bradyseism". Two uplift phases, each of 1.8 m, affected the area respectively in 1970-1972 and 1982-1984; both were followed by slow subsidence.
Vertical ground movements are accompanied by horizontal displacements, gravity changes, enhanced seismic activity during the strong uplifts and by variations of geochemical parameters in groundwaters, fumaroles and soil atmospheres.
The present paper takes into account the time series of radon (Rn) content, pH and temperature in groundwaters, ground deformations and gravity changes covering the 1982-1997 period. It is particularly focused on the analysis and interpretation of data covering the subsidence phase (1985-1997) following the crisis. Some almost contemporaneous variations and other interesting signatures have been observed in both the geophysical and geochemical behaviours. The relationships between groundwater features and geophysical activity have been ascertained in order to define common sources and mechanisms.

THERMO-VISCOELASTIC MODELS OF THE DEFORMATIONS AND GRAVITY CHANGES DUE TO THE MAGMATIC BODIES OF PRISMATIC SHAPE

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The paper presents theoretical formulae for the calculation of the stress and strain tensor components due to a source of heat of prismatic shape embedded in the viscoelastic halfspace (lithosphere) of the Kelvin type. The formulae for the gravity perturbation due to the volume dilatation connected with thermo-viscoelastic deformations is derived as well. Numerical results are presented in the graphs which show gradual approaching stress and strain to the steady state. The surface thermo-viscoelastic stresses are mainly of tensile type. Their values are well comparable with critical stresses required to cause creep or fractures of the surface. The displacement of the epicentral region causes a pronounced dome.

THEORY AND EXPERIMENTS RELATED TO THE SPREADING OF SOLIDIFYING MELTS

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The plane spreading of a viscous melt on a horizontal plate, driven by gravitational forces, for isothermal conditions already represents a problem with a free liquid/gas interface. This problem has been treated in literature both theoretically and experimentally. If the plate is kept at a temperature below the solidification temperature of the melt, we expect solidification of the melt in the proximity of the plate and, thus, a second free interface (solid/liquid) will be present in the problem.
Firstly, we discuss a set of experiments conducted with both high and low Prandtl number melts, namely Canauba wax and a low-melting metallic alloy.
Secondly, we develop models for the theoretical treatment of solidifying spreading flows for the limiting case of large Peclet numbers.
Thirdly, a carefull comparison of the experimental observations and the theoretical results is conducted.

USE OF EARTHQUAKES AND DEFORMATIONS AS REMOTE STRESS-METERS

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We investigate the relationship between intrusive events, ground deformation, and seismicity at Kilauea, Hawaii. The beginning of the 1983 Kilauea eruption was associated with a 2.1 meter fissure opening in the east rift-zone and a significant spatially-varying change of the south-flank seismicity. A general constitutive formulation [*Dieterich*, 1994] for earthquake occurrence is employed to invert changes of earthquake rates for Coulomb stress changes. An independent determination of the coulomb stress changes is obtained by a 3D boundary element modeling of the ground surface deformations. In this model, magma is emplaced in a dike-like vertical reservoir coupled with a freely sliding low-angle thrust fault. We find that the Coulomb stresses determined from seismicity correlate with an eruption process where a vertical dike propagated to the ground surface. A dike overpressure of 3MPa is determined for the eruption. The comparison between stresses determined by these two methods also helps defining the geometry of the south flank. This study demonstrates that the earthquake rates can be used quantitatively to determine stress changes associated to volcanic or seismic events. It also shows that the two types of inversion can be used complementarily to determine the stress sources: seismicity brings an information from the inside of the study volume whereas deformations give a precise information at the surface.

CRUSTAL STRUCTURE AND UNREST EPISODES AT THE ALBAN HILLS VOLCANO, CENTRAL ITALY

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The Alban Hills, a Quaternary volcano lying 20 km SE of Rome, last erupted 19 ka and has produced about 290 km^3 of eruptive deposits since 580 ka. Modern observations show that intermittent swarm activity originates primarily beneath the youngest phreatomagmatic craters. Results from seismic tomography allow identification of a low-velocity region, perhaps still hot or partially molten, more than 6 km beneath the youngest craters and a high-velocity region, probably a solidified magma body, beneath the older central volcanic construct. Thirty centimeters of uplift measured by releveling supports the contention that high levels of seismicity during the 1980s and 1990s resulted from accumulation of magma beneath these craters. The volume of magma accumulation and the location and amount of maximum uplift was probably at least 40×10^6 m^3 and 40 cm. Older levelings completed in 1891 and 1927 suggest earlier episodes of uplift. The magma chamber beneath the western Alban Hills is probably responsible for much of the last 200 ka of activity, is still receiving intermittent batches of magma, and is, therefore, continuing to generate modest levels of volcanic unrest. Bending of overburden is the most likely cause of seismicity, which have hypocenters above the 6-km-deep top of the magma reservoir. In this view, the most recent uplift and seismicity are probably characteristic and not precursors of more intense activity.

AN EMPIRICAL GREEN FUNCTION APPROACH TO STUDY THE RUPTURE OF FLUID-INDUCED MICRO-EARTHQUAKES

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The inversion method finds the best rupture model to explain directivity effects in P- and S-phases. We approximate the integral in the moment tensor representation using a sum over spatial and temporal centroids radiating at times calculated from the rupture models tested. The about 40 centroids used restrict the method to wavelengths larger that 1/6 of the maximal dimension of the fault plane. To ensure an overdetermined inversion problem and a good resolution we estimate only five source parameters; 2 fault dimensions, rupture duration, source strength and rupture direction. Two models are tested; uniform rupture on an elliptical fault and unidirectional rupture on a rectangular fault. Tension as well as shear faults can be handled. Additional to the separation between both models we distinguish between rupture and auxiliary plane. We use the seismograms of an observed small event with similar source mechanism as the studied event as empirical Green functions. Thus sensor site effects and sensor characteristics are unimportant.
We test the method on synthetic waveforms and on hydraulic induced microcracks in salt recorded with 8 piezo sensors. The physical mechanisms leading to induced seismicity during hydraulic fracture experiments are expected to be similar to the ones during magma-dike injections in volcanic areas. The preliminary results indicate, besides the small extension of the cracks ($20 - 40mm$), that the rupture velocity is small compared to pure tectonic earthquakes.

THE BROADVES SEISMIC EXPERIMENT: FIRST RESULTS ON THE LITHOSPHERIC STRUCTURE BENEATH THE CAMPANIAN REGION AROUND THE VESUVIUS VOLCANO

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During the summers of 1996 and 1997 two temporary arrays of broad band seismic stations were installed in the Campanian region around the Vesuvius volcano. The aims of this experiment (BROADVES) are to study the structure beneath this sector of the Southern Italy, and to analyse, for the first time using broad band instruments, local seismicity. The results of this experiment should give unique informations about the substructure of the Campanian volcanoes and, more specifically, about the mechanisms of local seismicity at Vesuvius, discriminating between volcano-tectonic earthquakes and low frequency, fluid-induced events. Each array was composed by 7 continuously recording Reftek digital seismic stations, equipped with 3 component broad band sensors (CMG-40T: 20 s: CMG-3T: 100 s or 360 s).We present the results of a teleseismic tomographic inversion for the P-wave velocity structure beneath the volcanic area and the surrounding Apenninic chain, carried out merging the data collected from the broad band arrays with the data recorded by the Italian Seismic Network. Furthemore, we present some preliminary results on the Moho geometry derived by the application of the receiver function technique.

LARGE SCALE RESISTIVITY IMAGING AT MERAPI VOLCANO

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Resistivity of geological structures is mainly controlled by their porosity, the resistivity of the fluids contained in them, and temperature. Highly porous rocks, extremely dry or saturated with ionic hydrothermal fluids, high temperature contrasts as well as good conductivity of alteration minerals make resistivity an extraordinarily informative quantity for structural investigation of active volcanoes. However, poorly accessible terrain and poor grounding conditions complicate the application of conventional resistivity technology on volcanoes and require a special design of field equipment, data enhancement, modelling, and inversion strategies. The paper presents the results and the technology of a dipole-dipole resistivity survey of nearly 3 km length and a depth of investigation of more than 800 m, set out radially along the west flank of Merapi volcano, Indonesia, between 1300 m and 2000 m above sea level. The resulting pseudosection shows a 2D vertical slice through the resistivity distribution reaching through a high-resistivity layer of unsaturated pyroclastica (rho > 1000 ohmm) into an extremely low-resistivity, presumably hydrothermal, zone (rho < 50 ohmm). The combination of a robust, portable, light-weight DC-transmitter especially designed for poorly accessible volcanic terrain and 24-bit data receiver technology (RefTek) represent an efficient method of data acquisition. Selective signal stacking and other signal enhancement procedures allow higher spatial resolution and greater depths of investigation. Cross-flank volcano resistivity monitoring will be discussed.

A MECHANICAL-THERMALFLUID-DYNAMICAL MODEL FOR CAMPI FLEGREI UNREST EPISODES: POSSIBLE EVOLUTION TOWARDS CRITICAL PHENOMENA.

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We develop a model for describing water flow in a porous medium under the effect of thermal and pressure gradients. The model simulates geothermal systems in calderas. Given the boundary conditions and the fluidodynamical properties of the medium, the model allows to compute, in stationary states, parameters characterising the flow, i.e., flow velocity, temperature and pressure distributions at depth, etc. The model is applied to investigate the effects of the local geothermal system on the unrest episodes at Campi Flegrei caldera. Using experimentally determined fluidodynamic parameters for the caldera rocks, it is shown that changes of water flow in shallow aquifers, under the effect of a pressure and/or temperature variations within of geothermal system can be very important in the genesis and evolution of unrest crises. In particular, they can strongly amplify the effect of pressure increase in the magma chamber on ground uplift. They can also explain the time scales of evolution of ground movements, in terms of transit times of the water front and of the connected temperature fronts due to advective transport . The validity of the approximations used in the monodimensional model, as well as the main evidences for dominant convective transport are discussed. On such grounds an integrated mechanic-thermalfluid-dynamical model is built, explaining the Campi Flegrei unrests.

A NEW TYPE OF SULPHIDE ORE DEPOSIT IN THE FIELD OF IGMIMBRITE VOLCAMIC ACTIVITY ABOVE THE SUBDUCTION SOME

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It is well known, that in the ignimbrite volcanic activity fields the Kuroko type sulphide deposits are manifested. The latter are developed in extentional regime in island arcs above subduction zones .The deposits occur within collapsed submarine calderas, after completing of the cycle of the ignimbrite activity, and are related to postcollapse extrusions of the ryolitic domes. In the Lesser Caucasus, in the Bolnisi ore district in the Upper cretaceous ignimbrite fields, within collapsed calderas two signif Icant nonferrous and copper-pyrite deposits occur. The geological and geo-chronological investigations let us as same, that these deposits could not belong to Kuroko type, because ore generation processes procureded before the ignimbrite ejection and before caldera collapse. The origin of these ore bodies took plase during the tumicsent stage, when the felsic magma intruded and formed magmatic chambers,that conditioned succeeding ignimbrite activity. These intrusives were the source of ore solutions for the deposits. W. E. Elstone (1992) and I.Rytila(1992) described tumiscent ore manifestation outside the caldera borders. The Madneuli and Tsiteli Sopeli deposits represent the only tumiscent economically sigTilficant deposits described within caldera structures. Thus, we propose to distingwish such type of deposit as Bolnisi type deposit.

EFFECTS OF STRESS FIELDS ON THE INTRUSION AND EXTRUSION FREQUENCIES OF CENTRAL VOLCANOES

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In rift-zone central volcanoes in Iceland, eruptions are frequent (typically one every several hundred years), of small volume (normally less than 0.1 km^3) and mainly fed by thin (average thickness 0.5 m) inclined sheets. In the rift zone outside central volcanoes, eruptions are rare (typically one every several thousand years) but of large volume (typically more than 1 km^3) and mainly fed by thick (average thickness 4-5 m) subvertical dykes. Boundary-element studies of magma chambers indicate that these empirical relations, as well as the formation of specific central volcanoes in the rift zone, can be explained by the stress fields around the chambers. Tensile stress concentration around the shallow source chamber of a central volcano leads to the segment containing the chamber rupturing, and the central volcano erupting, much more frequently, but with smaller intrusive and extrusive volumes, than the surrounding parts of the rift zone.

PHYSICAL SOURCE MODELS FOR HARMONIC TREMOR

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For over 18 hours, the tremor at Lascar volcano, Chile, was characterized by a harmonic spectrum with narrow peaks at a fundamental freqency of about 0.63 Hz and up to 30 overtones at exact integer multiples. Fluid dynamics offers at least three physical source models for this harmonic tremor, which produce repetitive, nonsinusoidal waveforms: The release of gas through a very small outlet (the soda bottle model), slug flow in a narrow conduit, and eddy shedding at obstacles or corners. These models represent different flow regimes, each with its own characteristic range of Reynolds numbers. For each model the fundamental frequency of the tremor is related to the Reynolds number for the flow. Combining the Reynolds numbers for each model with typical kinematic viscosities for the possible volcanic fluids -- magma, water, steam, air or some combination, at appropriate temperatures and pressures -- provides limits on such physical parameters of the volcano as the dimensions of the flow conduit and the flow velocity of the fluid generating the tremor. All three models imply that the tremor is generated by the movement of steam or water near the surface.

MAYON VOLCANO; PHILIPPINES: MODELIZATION OF STRESS BALANCE

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Mayon volcano is part of the Bicol Volcanic Chain, a peninsula in the southeast of Luzon island. The eruptive history during this century shows a nearly periodic behaviour: The volcano erupted almost every ten years.
During the last two eruptions indications for tidal triggering of activities were found. The pressure increase in the vent due to vesiculation was modelled assuming a temperature decrease of 2°C per year. The results were compared with the stress provided by the tidal forces (body tides and ocean tidal loading). It turns out that during a period of several days the small tidal forces may affect the stress balance considerably if the volcano is already in a critical state.

SLOW ROCK FRACTURE AS AN ERUPTION PRECURSOR AT SOUFRIERE HILLS VOLCANO, MONTSERRAT

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The onset of magmatic activity at Soufriere Hills volcano, Montserrat, was preceded by a tenfold increase in rates of seismic event. A new model of subcritical rock failure shows that the increase is consistent with the episodic growth of the feeding conduit at a rate controlled by progressive rock weakening. The preferred weakening mechanism is stress corrosion, for which circulating fluids chemically attack the country rock and promote failure at stresses smaller than the rock's notional bulk strength. Episodic failure may result from heterogeneities in bulk rock resistance or from variations in effective resistance due to the formation and failure of a damage zone ahead of the main feeder. Combined with traditional seismic monitoring techniques, the results highlight the potential of slow-cracking models for improving eruption forecasts.

NUMERICAL MODELING OF MAGMA WITHDRAWAL FROM COMPOSITIONALLY STRATIFIED MAGMA CHAMBERS

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Magma withdrawal from a compositionally stratified magma chamber is investigated using a physical model based on the mass, momentum, enthalpy and composition equations for an incompressible fluid with newtonian rheology. Magma viscosity and density are functions of temperature, composition and crystal content and are computed using the program MELTS (Ghiorso et al., 1994). The small density variations are accounted for through the Boussinesq approximation. Equations are solved in a two-dimensional domain adopting the Finite Element Method. The chamber is initially filled of two layers of magma with different composition and temperature. During the eruption, new magma enters from an inlet at the bottom of the chamber, while the resident magma is allowed to exit through a conduit located at the top. Different inlet geometries and mass flow rates are investigated in order to study magma mixing and the temporal variation of the composition of the erupted products. The chamber dimensions and the physical properties of the magma are prescribed similar to the pre-eruptive conditions of the 79 AD Vesuvius eruption.

MULTIPHASE FLOW MODELING AND SIMULATION OF EXPLOSIVE VOLCANIC PROCESSES

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Almost 15 years ago, the recognition of the multiphase nature of many eruptive processes opened a new research field in volcanology. This approach is based on the extension of the fundamental Navier-Stokes continuum mechanics equations to a multiphase and multicomponent mixture. According to this theory, different phases are treated as interpenetrating continua and the mass, momentum, and energy interphase transport terms are explicitly accounted for in the conservation equations. Constitutive equations of the dispersed particulate phases can be based on semi-empirical correlations calibrated by lab experiments as well as on the recently invented concept of granular temperature deriving from the extension of the dense phase kinetic theory of gases to particulate flows. Such a new variable allows the description of critical flow properties, such as solids pressure and viscosity, in terms of first principles. Different types of explosive volcanic events, such as collapsing columns, pyroclastic flows, dome and phreatic explosions have been simulated by multidimensional physical models based on the presented multiphase flow theories. Results highlight relevant mechanical and thermal non-equilibrium effects between the different phases of the mixture that can affect the large-scale dynamics of the explosive process.

Comparative study of pyroclastic deposits in Campi Flegrei (Southern Italy): evidences of recurrent eruptive and depositional mechanisms.

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The intra-calderic explosive activity of Campi Flegrei produced tens of mono-genetic volcanoes. A comparative analysis of the most representative deposits suggests that the eruptive and depositional conditions of the different deposits were recurrent. Several evidences indicate a common explosive magmatic background of most deposits types modulated by different degree of interation with shallow water in determined the style of eruption. The abundance of fresh, completely vesiculated fragments also in phreatomagmatic deposits as well as the presence of different order of vesicles and coalescence indicate that the fragmentation took place only in the very final stage of magma ascent and vesiculation. The relations between vesicle walls and broken surface of the clasts suggest that magmatic and hydromagmatic fragmentation both occurred after a near complete magma vesiculation. According to these evidences and considerations a general two stage model of the intracalderic, explosive activity forming the monogenetic volcanoes in Campi Flegrei consists of : a) rapid magma rise for high bubble growth rate at low confinig pressure in a shallow magma reservoir; b) continuous or pulsating magma water interaction possibly due to local decompression or coduit instabilities that allowed and avoided access of water to the conduit.

COSEISMIC DISPLACEMENTS AND CREEPING ALONG THE PERNICANA FAULT (ETNA, ITALY) IN THE LAST SEVENTEEN YEARS: A DETAILED STUDY OF A TECTONIC STRUCTURE ON A VOLCANO

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The Pernicana fault is a well evident tectonic fault located on Mt. Etna (Sicily). Movements across this structure have been monitored, in the last seventeen years, by a levelling network owned by Osservatorio Vesuviano. During the monitoring period, the network has recorded coseismic displacements associated to earthquakes of magnitude 4 to 5, as well as displacements not related to earthquakes. We present a detailed study of the displacement data, aimed to model the geometry and mechanism of this fault, as well as the size and mechanisms of individual earthquakes. The total recorded displacements during the last seventeen years are well interpreted by a single, homogeneous rectangular normal fault, with dislocation and size corresponding to a magnitude 5.7 earthquake, thus revealing an intense dynamics along such a fault. The heterogeneous slip distribution associated to the two largest earthquakes has been also inferred from coseismic displacement data. Seismic moments of such earthquakes turn out to be considerable higher than reported in seismic bulletins (about 1 degree of magnitude). The results obtained here evidence the high potential of levelling data in the detailed study of a rather peculiar kind of tectonic structure on a volcano.

ROCK DEFORMATION AND FRACTURING PROCESSES DUE TO NONLINEAR SHOCK WAVES PROPAGATING IN HYPERTHERMAL FLUID-SATURATED DOMAINS

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An analytical model for rock deformation and fracturing processes due to nonlinear waves of temperature and pressure, evolving with particularly large velocities in a fluid-saturated rock overlying a hyperthermal aquifer is discussed here. As in recent studies the upper fluid-saturated horizon is considered homogeneous, thermo-elastic and isotropic in a one-dimensional formulation. Regarding the nonlinear wave generation mechanism, at the boundary between the two horizons, the hot fluid from below is envisaged being forced upwards by a pressure gradient, thus generating strong pressure and temperature perturbations. With these considerations and in order to model wave induced rock deformation and fracturing processes, we assume a continuous temperature and pressure dependence of models parameters such as fluid diffusivity and fluid-rock thermal diffusivity. The solution we obtain is a strong shock wave corresponding to nonlinear fluid migration mechanisms, in turn enhanced by the flow through the induced fractures in the horizon overlying the aquifer. We emphasise that once such a process starts, it may be amplified, and also trigger explosive eruptions. This model essentially provides a theoretical tool for interpreting such geophysical effects, for example for calderas such as Raboul, Long Valley, Campi Flegrei where surface displacements and phreatic eruptions have occured.

NUMERICAL MODELING OF MAGMA ASCENT ALONG VOLCANIC CONDUITS

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The steady, one-dimensional, multiphase non-equilibrium ascent of magma along the volcanic conduit during explosive eruptions is numerically simulated by thermofluid dynamic modeling. The relevant magma properties (gas solubility, density, viscosity) are allowed to change along the conduit due to mass transfer between the phases, and are calculated on the basis of the chamical composition of magma in terms of ten major oxides plus dissolved volatiles and of an equation of state for the real behavior of the gas phase. The model accounts for the presence of water and carbon dioxide exsolving from the liquid, and is based on the coupling between fluid dynamics and the most advanced models for the magma properties. Magma fragmentation is assumed to occur at either a critical value of the gas volume fraction, or at a level in the conduit where the elongational strain rate overcomes the critical strain rate imposed by the magma structural relaxation time. The model reveals many features of the magma ascent dynamics in explosive eruptions, and can be used to investigate the role of the different parameters involved in the ascent process, or to forecast the volcanic hazard by defining the conduit exit conditions for a given set of initial (magma chamber) conditions.

PRELIMINARY RESULTS FROM A BROADBAND SEISMIC EXPERIMENT AT STROMBOLI VOLCANO, ITALY.

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During September-October 1997 a joint Italy-US team conducted a large-scale broadband seismic experiment to investigate the long-period signals associated with the ongoing explosive activity at Stromboli volcano, Italy. 21 three-component, 60-s Guralp CMG-40T sensors were deployed in three circular patterns surrounding the active craters at altitudes of about 100, 500 and 750 m. During four separate days of data acquisition, we recorded continuosly 7 to 24-hour-long intervals of volcanic signals, thus obtaining the most detailed broad-band data set ever collected on an active volcano. Preliminary results from analyses of selected waveforms in the 2-50 s period range show the existence of at least two distinct sources repetitively acting in time. Polarization vectors inversion clearly indicate that both sources are constrained within a shallow volume located N-NW beneath the active vents. Ground motion observed prior and during the summit explosions is consistent with an inflation followed by a rapid deflation of the shallow plumbing system. Future goals to be attained include Green's functions calculation using a 3-D finite difference approach and inversion of waveforms for moment tensor analysis.

VISCOUS FLOW IN A CHANNEL: APPLICATION TO LAVA FLOWS

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We propose a 3D model describing a channeled lava flow in the proximity of the eruption vent. We describe the lava as an isothermal Newtonian liquid flowing in a rectangular channel down a constant slope. The flow velocity is calculated by an analytical steady-state solution of the Navier-Stokes equation. The surface velocity and the flow rate are calculated as a functions of the flow thickness for different flow widths and the results are compared with those of a 2D model: it appears, for a typical Etna's lava flow, that the influence of the levees on the flow dynamics is not negligible when the flow width is less than 25 meters. The model predicts the volume flow rate corresponding to the surface velocity taking into account that both depend on the flow thickness. We propose a model for the evaluation of the effusion rate by knowing the lava flow width, the slope of the topography, the lava density, the surface flow velocity and either the lava viscosity or the flow thickness.

Seismic activity at the Solfatara crater (Campi Flegrei caldera) shows different sources mixing of fumarolic fluids and possible parameters to forecast the occurrence of new earthquakes.

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Here we describe temporal variations of noble gas and carbon isotopes and chemical data of fluids collected from 1990 to 1994 at the Bocca Grande fumarole (Solfatara crater), before the occurrence of a seismic swarm. After more than seven years of quiescence: a sudden vertical ground deformation and a seismic swarm of 100 quakes with a Mmax=1.5 with epicenter located beneath the Solfatara crater, were recorded from August 23 to 25 1994. Isotopic composition of He, Ne, Ar and C (from CO2) and chemical composition of He, Ne, Ar, H2, CH4 and N2 have been analysed from fumarolic fluids. To date these isotopic ratios have not been used as precursors of earthquakes, although several cases have been reported in which helium isotopic ratio was used to interpret volcanic unrest. All the analysed isotopic ratios, chemical species and a calculated equilibrium temperature show a significant change a few months before the occurrence of the seismic activity and ground deformation, followed by a sudden return to values recorded prior the swarm. Migration towards the surface of deep (and hotter) gas phase related to crustal and magmatic sources with the following decrease of the surficial atmospheric component is the cause of such wide variations.

A NEW PRESSURE VESSEL FOR MAGMA- AND ROCK-H2O INTERACTION STUDIES

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A already recognized on volcanoes, water under pressure coming in contact with magma bodies or hot rocks may interact explosively originating phreatomagmatic or phreatic eruptions if some boundary conditions between the two media are present. Because of experimental difficulties, preceeding studies have been mainly directed to reproduce the natural processes and products using artificial analogues without much reference to P,T,Xi, and gases real conditions. Therefore it has been designed and realized an experimental apparatus able to perform interaction experimentsup to Pmax of 200 Mpa and Tmax of 1200C using natural rocksof known compositions. The interaction cell is contained within a two liters IHPV (internally heated pressure vessel) and is equipped with a membrane allwing volume variations due to H2O liquid-vapor transition. The sample, in form of a rock cylinder 20x60mm, is confined by a Pt crucible inside the cell and injected via a Pt capillary tube of H2O with known quantity and pressure. The pressure differenzial between the inside and the outside of the cell can be also controlled:i.e. lowering of the cell outside pressure can trigger the explosive magma-water interaction. Experiments are in progress on magma-H2O interaction processes at Vulcano Is. And on liquid-vapor H2O transition controlling bradisisma in Campi Flegrei area.

STRESS CHANGES ASSOCIATED WITH VOLCANIC SOURCES: AN EXAMPLE FROM KILAUEA RIFT ERUPTIONS.

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The dynamics of volcanic sources involves high strain and stress changes in the host rocks. Strong perturbations to the local stress regime are then produced, which can attain much larger values than the regional stress field. Modeling of such perturbations can be hence of fundamental importance to interpret the evolution of volcanic unrests and, in particular, the seismicity generated during unrest episodes. In this work, an analytical method, based on the formulas by Okada (1992) is developed to simulate strain and stress changes associated to dynamics of volcanic sources such as: magma chamber overpressure, dike and rift opening. Magma chamber overpressure is simulated by isotropic point sources, dike and rift opening is simulated by rectangular, finite faults with dislocation normal to the fault plane. In order to study the influence of volcanic sources on the earthquake generation, Coulomb stress changes are computed for several sources of different depth and geometry. Such changes can be computed both on fixed fault plane orientation and on the optimally oriented planes, defined as the planes with maximum total Coulomb stress, regional plus local. The obtained results give insight on the expected locations and mechanisms of seismicity associated to volcanic sources. An example of application of the method to the study of the seismicity of the South flank of Kilauea is presented. Results show that such seismicity, and the seaward movement of the southern flank, can be interpreted in terms of stress changes associated with north-eastern rift intrusions and eruptions.

ST7 Nonlinear processes in the ionosphere and magnetosphere (co-sponsored by NP)

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FIRST TEST MEASUREMENTS OF ARTIFICIAL ULF SIGNALS AT THE LONG DISTANCE 1500 KM

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During September 18-19, 1993, RIPR, St.-Petersburg and NIRFI, N.Novgorod, Russia performed the first measurements of artificial ULF signals in the frequency range 1-5 Hz at the distance of 1500 km between transmitter and receiver. The ULF Facility, located at the Kola peninsula, near Murmansk, Russia was consisted of 55-km powerline with radiation current of 150 A and was grounded at both ends. The operating frequencies were 1.3, 2.6 and 5.2 Hz (20 min "on",10 min "off") during each of three 2-hour cycles a day, evening and early morning conditions. The receiving site was located near N.Novgorod and provided the measurements of two H_{N-S} (H) and H_{E-W} (D) magnetic components. The observed magnetic field strengths and magnetic vector polarizations were found to be in line with the simple waveguide-cavity theory predictions for daytime conditions and to be in a dramatic discrepancy for nighttime ones. The measured distinctions can be explained by a significant influence of an additional portion of the magnetic signal ducted into MHD-ionospheric waveguide and by ionospheric resonance properties (Ionospheric Alfven Resonator) above transmitter and receiver.

FINITE ELECTRON MASS IN MAGNITOHYDRODYNAMIC THEORY. STRONGLY NONLINEAR PERIODIC WAVES AND SOLITON.

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Starting from the multi fluid hydrodynamic approximation we have got the generalazation of Ohm's Law in usual magnitohydrodynamic (MGD) theory. MGD approximationIt is well known to be valid only for low frequency perturbation, i.e. that frequency should be much less ion hyrofrequency ω_{Bi}. Our equations take into account both Holl effect and the finite value of electron mass. It is allow us to describe all low frequency spectra ($\omega \leq \omega_{Be}$) in 2-component low density ($\omega_{Be} \ll \omega_{pe}$) plasma. We have got also an exact solution of generalized MGD equations. There are the waves (periodic and soliton-like) traveling perpendicular to external magnetic field. We have calculated maximum amplitude of magnetic field for that wave. The nature of the wave dispersion is essential electro-magnetic, because plasma is localy quazineutral for any wave amplitude.

EXPERIMENTAL INVESTIGATIONS OF THE IONOSPHERIC ALFVEN RESONATOR FROM ELECTROMAGNETIC NOIS BACKGROUND OVER THE SOLAR CYCLE OF 1985-1995

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Based on long-term observation of the resonance structure in the magnetic field spectrum (RSS), recorded in the frequency range of 0.1-10 Hz over one complete solar cycle (11 years), it was found, that the resonance conditions for the Alfven waves in the ionosphere (ionospheric Alfven resonator) are determined by the level of the solar activity. RSS are regulary observed in years of minimum solar activity, and are practically absent in years of maximum solar activity. These experiments were performed during 1985-1995. It was shown thereby, that the consideration of the ionospheric Alfven resonator will allow to explain the dependence of the RSS on the solar activity.

FIRST EVIDENCE OF SPECTRAL RESONANCE STRUCTURE (SRS) OF ULF BACKGROUND ELECTROMAGNETIC NOISES AT THE POLAR REGION.

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A high-sensitive, two component induction magnetometer has been used for measurements of natural electromagnetic noise in the frequency range 0.1 - 10 Hz. Observations were carried out at the receiving site Kilpisjarvi (L = 6) during the 1-st Finnish EISCAT-Heating Campaign in November, 1993. We have examined the average magnetic spectra for four magnetic polarizations (linear, N-S and E-W, and circular, R and L) with spectral resolution of 0.1 Hz and time resolution of 15 min. During at least four out of twelve nights covered by measurements, clear evidence of Spectral Resonance Structure (SRS) was obtained in the magnetic spectra. The SRS is appeared in a deep sinuousform modulation of noise spectral amplitude along the frequency axis with 3-4 spectral maxima and distance between ones, varied over period of measurements from 0.5 to 1.5 Hz. The temporal variations of SRS pattern differed from those of midlatitude ones, as observed near N.Novgorod, Russia but were in a good accordance with EISCAT measurements of electron density in the F-layer of ionosphere.

ELECTROMAGNETIC REMOTE SOUNDING OF RESONANCE PROPERTIES OF POLAR IONOSPHERE IN THE ULF FREQUENCY RANGE 0.1 - 5 HZ WITH USING OF HF POWERFULL HEATING FACILITY.

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Measurements of ULF (0.1-5 Hz) artificial signals excited in lower ionosphere by amplitude modulated HF (4-6 MHz) radiation from "Tromse" heating Facility were performed by joint Russian-Finland scientific team during the 1-st Finnish EISCAT-Heating Campaign in November, 15-19, 1993. At the receiving site "Kilpisjarvi"(100 km from Facility), four magnetic field polarizations were available in measurements - two linear and two circular ones. Clear sinuousform amplitude-frequency responce of signals was detected. The distance between two neiboring amplitude maxima or minima along frequency axis varied from 0.5 to 1.5 Hz with dependence on daytime conditions of experimental cycles. This resonance frequency pattern was more visible for artificial signals (derived by coherent integration) then the exhibition of Spectral Resonance Structure of background magnetic noises, derived from averaged noise spectra in the same time and which is discussed in accompanied communication.

PARAMETRIC DECAY OF ELECTROMAGNETIC PUMP WAVE IN TWO-DIMENSIONAL INHOMOGENEOUS PLASMA

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Due to the action of strong HF electromagnetic waves artificial plasma irregularities appear in the ionosphere which have an influence on various nonlinear effects, e.g. stimulated electromagnetic emission (SEE). Different processes including decay instabilities are responsible for the peculiarities of the broadband spectrum of the SEE. Up to now decay instabilities in relation with SEE were discussed neglecting longitudinal inhomogeneity of the medium and wave propagation along the magnetic field line. These two factors may reduce considerably the wave interaction. We consider the decay instability of the EM pump wave into upper hybrid (UH) and lower hybrid (LH) waves as a first step in the creation of the downshifted maximum (DM) in the SEE. In distinction from previous papers the case when UH waves are trapped in weak plasma enchancements along the magnetic field line is investigated. It is shown that transversal inhomogeneity of the medium is also very important and should be taken into account. The linear stage of instability is analysed and the frequency range of the excited UH waves is found. It is shown that such spectrum is similiar to the spectrum of DM in SEE.

ON THE PEDERSEN CURRENT CARRIED BY ELECTRONS

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According to text books the Pedersen current is carried by ions and has a maximum flow around an altitude of 125 km. When the perpendicular electric field in the ionosphere gets sufficiently large, then the Hall current at heights around 108 km becomes unstable. The excited plasma waves reflect VHF radio waves leading to the so-called radio aurora. Farley (1963) and Buneman (1963) first treated the linear theory of this current instability. From observations using incoherent scatter radars it is also known that during such strong electric field events the electrons in the E region get heated and a substantially enhanced temperature is maintained against the relatively intense cooling processes in the atmosphere. In this talk we show, that then, as the conservation of energy implies, the wave-electron interaction in the quasi-linear stage must lead to a Pedersen current carried by electrons. Both, the heating and deflection of the electron drift vector from the ExB direction limit a further growth of the waves. Using EISCAT observations and models for the cooling processes, we estimate the electron Pedersen current to amount to about 20 percent of the ion Pedersen current once the instability threshold is exceeded. The ionospheric instability mechanism considered by us might play a triggering role for the excitation of other instabilities and reconfiguration in the ionosphere-magnetosphere coupling.

DYNAMICAL RAY FOCUSING IN INHOMOGENEOUS PLASMA

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Ray dynamics is investigated by Hamiltonian mechanics method. For certain values of the parameters of smooth and periodic inhomogeneities, it is possible a dynamical ray focusing.

It has been determined the conditions on which rays oscillate around the position of the synchronous ray, and there takes place a dynamical ray focusing.

The focusing caused by a periodic inhomogeneity is similar to the secondary resonance in the resonance theory of perturbation in Hamiltonian systems. On certain conditions, there may take place an overlap of the regions corresponding to nonlinear resonances in the phase space, and this results in spatial fluctuations of rays becoming chaotic.

INFLUENCE OF PLASMA DENSITY FLUCTUATIONS ON PLASMA-BEAM INTERACTION

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It is investigated the instability of the beam that moves in plasma with the density which stochastically varies in space or time.

The dynamics of any order of moments is studied when the plasma density changes in space or time. It is shown that every sequential moment grows faster than the previous one. The increment of the second moment exceeds the increment of the regular part of the signal more than two times. The result of this dependence of increment is punctuate character of instability growth and the appearance of some critical length of interaction area where the amplification of the regular signal is possible yet. The maximum time what need for signal destroying by fluctuations is calculated.

CHORUS EMISSIONS PRODUCED BY A BACKWARD WAVE OSCILLATOR IN THE MAGNETOSPHERIC CYCLOTRON MASER

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The influence of the inhomogeneous geomagnetic field on the backward wave oscillator generation regime in the magnetospheric cyclotron maser is considered. This regime is due to the absolute instability of a quasimonochromatic whistler wave in the near-equatorial region of the Earth's magnetosphere caused by energetic electrons with a step-like deformation of the distribution function in parallel velocity. Such a deformation is formed due to the quasi-linear interactions of energetic electrons with noise-like emissions having an upper frequency cutoff. In this paper, it is proven that the absolute instability leading to the backward wave oscillator generation regime can be achieved for magnetospheric conditions. For this, the linearized self-consistent equations for the wave amplitude and energetic electron resonant current in a parabolic external magnetic field are solved. The spatial profile of a whistler mode wave formed due to cyclotron resonant interactions is determined; threshold parameters for the absolute instability are obtained. The implications for chorus generation in the magnetosphere are discussed.

RECENT DEVELOPMENTS IN THE CHARACTERIZATION OF NONLINEAR WAVE PHENOMENA IN SPACE PLASMAS

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Progress in understanding nonlinear phenomena in space plasmas is intimately related to our capacity of characterizing such phenomena by means of physically relevant concepts. During the last decade, many developments in that field have shown that it is still open to considerable progress. Some of these novel concepts are reviewed here.

The emphasis is put on a series of concepts that are intimately related : topological properties (scaling laws, self-similarity), complexity (hierarchical structures) and self-organisation (coherent structures). Through a review of recent results obtained in space plasmas, the inference of these properties from experimental data and their relevance (or irrelevance) for the study wave phenomena will be discussed.

A DYNAMICAL STUDY OF INDUCED SCATTERING

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We investigate dynamical properties of a simple model of electrostatic wave-wave interaction in the induced scattering limit (case of an isothermal plasma), without making use of the random phase approximation (Zakharov, V.E., Musher, S.L. and Rubenchik, A.M., Sov. Phys. JETP 42(1), 80-86 (1975)).

ON THE NONLINEAR TRIGGERING OF VLF EMISSIONS BY POWER LINE HARMONIC RADIATION

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The Jan 1993 VLF campaign by Sodankylä Geophysical Observatory at Porojärvi in Northern Finland has produced a remarkable data set of VLF emissions. The data is characterised by a high incidence of power line harmonics, and also by frequent echoing of events up to six times. The PLHR lines are identified as being due to the Finnish power system, since the dominant lines occur at f=50·(12n±1) Hz. There is clear evidence that these PLHR lines penetrate the magnetosphere and trigger VLF emissions in the equatorial zone. A wide variety of emission forms are noted, namely steep multiple risers, upward and downward hooks. In this paper we numerically simulate emissions triggered at 2950, 3650 and 4150 Hz. The code is a 1D EM code using the Vlasov Hybrid Simulation technique (VHS). It assumes parallel propagation and a hot anistropic electron distribution function giving linear growth rates ~60 dB/s. The code has a bandwidth ~50 Hz, and permits linear spatial variations of wavenumber. Making plausible choices for L shell and equatorial cold plasma density, successful simulations have been made of PLHR triggered risers, fallers and upward hooks. Simulated sweep rates ~1 kHz/s were in very good agreement with the data. The simulations also revealed key aspects of the phenomenon of triggered VLF emissions. When the equatorial linear growth rate exceeds a threshold 50 dB/s the plasma becomes nonlinearly absolutely unstable. At the end of the linear growth phase, a stable nonlinear structure termed a generation region (GR) is set up. Risers and fallers have different distinct GR structures, and hooks result when GR type changes. Interestingly the basic physics of VLF emissions is almost the same, wether one is at L=3, 4, 5, 6 or 10.

PULSATING AURORAS AND THEIR CONNECTION WITH VLF EMISSIONS OBSERVED IN NORTHERN FINLAND

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Pulsating aurora is a substorm recovery phase phenomenon and is mainly seen on the morning side of the auroral oval. The pulsating precipitation of the auroral electrons is a consequence of wave-particle interactions in the magnetosphere close to the equatorial plane. These wave-particle interactions between whistler-mode VLF waves and magnetospheric electrons lead to a pitch angle diffusion of the electrons and this can lead to precipitation of the electrons into the ionosphere. This pulsating precipitation is then seen as auroral intensity pulsations. Models of pulsating aurora are based on the cyclotron instability of trapped particles.

Simultaneous auroral and VLF measurements have been made during EISCAT and VLF campaings in Northern Finland every winter since 1990. Auroral recordings are made using a low-light-level TV camera. VLF signals (200 Hz - 9.2 kHz) detected by two loop antennas are recorded on audio tracks of the same video tape as auroral measurements. TV recordings are analyzed by digitizing them and VLF recordings are analyzed by an analysis package developed at the Sodankylä Geophysical Observatory. The measurements presented here were made at Porojärvi (69.17°N, 21.47°E) in 1993, 1997 and at Kalkkoaivi (68.73°N, 22.11°E) in 1994. Here we present some results of the connection between pulsating auroral patches and VLF emissions.

MODULATIONAL INTERACTION OF LOWER-HYBRID WAVES AND FORMATION OF COHERENT STRUCTURES IN THE MAGNETOSPHERE

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A universal nonlinear formalism is presented for the description of the dynamics of random and regular lower-hybrid fields. This formalism allows us to obtain the integral equations describing the modulational instability of spectra of lower-hybrid waves, find the rates and thresholds of the instability. It is shown that the appearance of the instability thresholds is possible only for the spectra which occupy the whole region in the wave vector space where the waves can exist. The instability is investigated in detail for the parameters of the waves and the magnetospheric plasma inherent in the conditions of the observations carried out by the satellite Freja. It is shown that the coherent field formation and, correspondingly, the formation of the state of strong turbulence in the magnetospheric plasma is connected with the development of the modulational processes. In particular, the magnitudes of the threshold density of the lower-hybrid fields, which characterize the process of excitation of regular fields in the Earth's magnetosphere and have been observed by the satellite Freja, are explained by considering the thresholds of the modulational instability.

ON PARTICLE ACCELERATION BY LOWER HYBRID TURBULENCE DURING IONOSPHERIC MODIFICATION EXPERIMENTS

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The acceleration of ions and electrons by lower hybrid turbulence is widely used for the interpretation of particle spectra in space and laboratory plasmas. On the other hand, excitation of the lower hybrid turbulence appears to be a necessary element of the generation mechanism of the outshifted plasma lines and stimulated electromagnetic emission, observed during the injection of intense HF radiowaves into the ionosphere. It is the aim of our paper to define the parameters of the accelerated electron and ion spectra characteristic of the ionospheric modification experiments in the polar ionosphere.

MAGNETOSHEATH'S MODEL IN THE CGL APPROXIMATION

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Parameters of the solar wind plasma and magnetic field in the magnetosheath in dependence on the IMF orientation are calculated for an anisotropic plasma in the CGL-approximation. There is shown that for given parameters of the solar wind, the temperature anisotropy of the magnetosheath plasma results in a decrease of the magnetic field intensity and of the plasma density at the magnetopause, especially for a southward IMF. Influence of the pitch-angle diffusion of protons on the magnetosheath parameters is discussed.

DEMODULATION OF HF RADIO TRANSMITTER SIGNALS BY THE POLAR ELECTROJET

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The ionospheric demodulation of modulated signals from HF broadcasting transmitters by the polar electrojet is considered. The main effect is caused by the formation of an ionospheric travelling wave antenna. This antenna radiates demodulated ELF/VLF waves in two directions, one of which coincides with the line connecting the broadcasting transmitter with the ELF/VLF receiver, and the other is the mirror image of this line relative to the direction of the ionospheric current. In this paper, attention is paid to the demodulation effects from the curved and non-stationary electrojet. It is shown that the curvature and temporal variations of the polar electrojet can lead to focusing or defocusing of the demodulated ELF/VLF signal, causing fast variations of its amplitude and polarisation. Quantitative estimates of these effects are presented.

THE ROLE OF THE ELECTRON-TO-ION TEMPERATURE RATIO AND TRANSIENT ELECTRONS IN THE LINEAR STABILITY OF THE QUASI-NEUTRAL SHEET TEARING MODE

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The linear stability of the tearing mode in the magnetotail current sheet with nonzero normal component of the equilibrium magnetic field first obtained by Lembege and Pellat [1982] considered the electrons to be trapped in the current sheet. The sufficient stability criterion severely limits tearing instability, interpreted as due to electron compressibility. The electron population in the current sheet however consists of trapped as well as transient populations. The integral equation for the perturbed electron densi ty including both trapped and transient populations is obtained within the drift kinetic approximation. It is shown that due to the transient population the electrostatic contribution to the flux tube integrated electron density does not vanish, but dominates at sufficiently small electron temperature. The formation of the plateau in the local density profile along the field line at sufficiently small T_e/T_i is demonstrated and a new sufficient criterion of stability is obtained. As compared to the original criterion of Lembege and Pellat [1982] the stability condition is reduced by a factor of $(3T_e/T_i)^2$. Thus marginal stability state may be reached for sufficiently cold electrons as noted earlier by Schindler [1974].

SPRITE EFFECTS ON THE IONOSPHERE

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Sprites and Elves are brief luminous flashes, occurring over mesoscale convective systems at altitudes of about 50 – 90 km and preceded by strong tropospheric discharges. Their mechanisms are believed to be the direct heating of free electrons up to a few eV and the breakdown of the atmosphere (at heights where the density is sufficiently low) due to the large electromagnetic and quasi-electrostatic fields, or/and the runaway breakdown initiated by cosmic rays. These strongly nonlinear processes are associated with a large transient current and convert a part of the LF – HF energy, as well as a part of the electrostatic energy of the tropospheric discharge, into the energy of the transient ULF – ELF radiation (*Sukhorukov et al.*, GRL **23**, 2911, 1996; *Sukhorukov and Stubbe*, GRL **24**, 829, 1997; GRL **24**, 1639, 1997). The energy conversion results in an unusually effective excitation of a number of the large-scale electromagnetic resonance phenomena in the Earth environment, such as the Schumann resonances and the transversal resonances of the Earth-ionosphere cavity, and the Alfven resonances in the upper ionosphere. A review of these and of a number of other Sprite-related nonlinear phenomena in the ionosphere, already discovered or predicted, will be given.

LINEAR AND NONLINEAR PROPERTIES OF ALFVÉN WAVES IN PLASMAS CONTAINING HIGHLY CHARGED IMPURITIES OR DUST

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Processes in dusty plasmas are being studied intensively because of their importance for a number of applications, in particular in plasmas of the Earth's environment.
The dust affects plasma collective properties in many ways. The simplest effects are due to the charged dust grains carrying a proportion of the negative charge of the plasma. Even if this proportion is quite small and the dust dynamics is ignored, it can have a large effect on propagation of some waves (e.g., hydromagnetic Alfvén waves at frequencies below the ion-cyclotron frequency). We consider dispersion characteristics of low frequency electromagnetic waves propagating in a magnetized plasma with immobile dust grains and finite electron temperature. Modification of the Alfvén resonance absorption mechanism due to the presence of the dust is discussed. Nonlinear effects in propagation of Alfvén waves parallel to the external magnetic field are considered, and surface Alfvén waves are discussed. Also, formation of shocks in dusty plasmas is examined.

COLLECTIVE CHARGING PROCESSES IN DUSTY PLASMAS

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Processes in dusty plasmas are being studied intensively because of their importance for a number of applications, in particular in plasmas of the Earth's environment.
The dust grain charge is mostly determined by plasma currents. We focus our attention here on this charging machanism, and consider its influence on plasma waves. The main difference of dust particles from heavy ions is that the dust charge is not fixed. Thus plasma collective perturbations lead to dust charge fluctuations which in turn affect the plasma waves. Physical processes with frequencies of order or less than the dust charging frequency are strongly affected by the dust charge fluctuations. The kinetic theory of a dusty plasma taking into account the dust charge perturbations is discussed.

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NONLINEAR INTERACTION OF WHISTLER WAVES WITH A MODULATED THIN ELECTRON BEAM

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The nonlinear theory of a thin modulated electron beam interaction with a monochromatic whistler wave is considered. The self-consistent set of differential equations describing the wave amplitude evolution and the beam particles motion has been solved by a computer code. We discuss here the results issued from the numerical solution of the differential system, and namely the physical features of the nonlinear beam-wave interaction (trapping, slowing down of the beam, wave damping, multiple bunching, beam focusing) as well as the influence of the physical parameters on the wave emission: beam energy and density, initial beam velocity distribution and beam current modulation. We have shown that the trapped particles are the source of the emission; they are decelerated in phase with the wave and remain in Cherenkov resonance with it owing to a nonlinear shift of the parallel wave number. No quasi-periodic exchange of energy between the wave and the particles has been observed.

Self-affine fractal dynamics of the activities of the Sun and magnetosphere of the Earth

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At the analysis of dynamics of solar (international SunSpot Number - SSN and SOLAR RADIO FLUX 10.7 sm - SRF) and geomagnetic (Ap- and Dst-indexes) activities (everywhere - daily average meanings for the period with 1960 for 1996 years) within the framework of the concept of the stochastic fractals with the methods of the Hurst (H) and calculations of fractal dimension on a covering it is shown, that chaotic dynamics of all indexes (without periodic components of 22-year's cycle) - self-affine stochastic fractals: H(SSN)=0.74, H(SRF)=0.82, H(Ap)=0.63, H(Dst)=0.80. Are considered the fractal dimensions and statistics of distribution of characteristic time's intervals for all processes. Is shown the dynamics of dimensions in a cycle of solar activity. Fractal properties of SSN correlate with fractal properties Ap, and SRF correlates with Dst. Statistics of time's intervals various for all indexes. Is shown that the minimum by derivative from dynamics of yearly average meanings of SSN corresponds to a maximum of fractal dimension of geomagnetic activity and vice versa. Generation chaotic components on the Sun are not connected to generation periodic components of solar activity. Periodic component of activity of the Sun influences on chaotic dynamics of geomagnetic activity. Annual dynamics of fractal dimensions of SSN (SRF) in dynamics of geomagnetic activity is not observed. Annual dynamics of fractal dimension Ap correlates with dynamics of yearly average meanings Ap, but for SSN, SRF and Dst such correlation is not observed. Marked by Hurst the fact, that the nature chooses $H \neq 0.7$ in global situations, finds the confirmation in indexes of the activity of the Earth and Sun.

NP5 Vortex dynamics

Conveners: Dritschel, D.G.; Zeitlin, V.

VORTEX STATISTICS IN TWO-DIMENSIONAL TURBULENCE

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We discuss the statistics of the vortex population and the time dependence of the statistical quantities in numerical simulations of freely decaying 2D turbulence with resolution 4096*4096 grid points.

REGULAR FORMATION OF EDDIES IN THE INTERMEDIATE LAYER

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The response of a 2.5 layer ocean model to localized injection of intermediate water on a beta-plane is studied in detail. The work is motivated by the recent finding of less saline submesoscale coherent vortices at the intermediate depth near the North Pacific Subarctic Front. Numerical experiments have demonstrated that three dynamical regimes exist. When the injection rate is small, linear baroclinic long Rossby waves are excited as expected. Increasing the rate leads to shedding of weakly nonlinear vortices. When the rate is increased up to $1.0 \times 10^6 m^3 s^{-1}$, however, anticyclonic lenses of the intermediate water are shed regularly. Those lenses travel westward with a speed several times faster than the linear long Rossby wave speed. It is shown that the westward speed is much influenced by the anticyclonic vortex motion generated in the surface layer. Inclusion of the surface layer effect explains the lens propagation quite well.

ROSSBY WAVE DYNAMICS ON SMOOTH CIRCULAR VORTICES: THEORY AND APPLICATION TO THE POLAR VORTEX

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Building on recent work that developed a theory for vortex waves, this work goes still further by developing a complete theory of the linear initial-value problem for vortex Rossby waves on both the f-plane and the beta-plane in the vicinity of the pole. The theory is restricted to circular basic state vortices possessing an extrema in the tangential wind. New conservation laws are developed which give exact time evolving bounds for disturbance kinetic energy. In general, initial disturbances are shown excite two regions of maximum wave activity. At the extrema of these barotropic stable wind profiles and for a certain range of wavenumbers, the vortex Rossby dynamics are shown to become fundamentally nonlinear for all initial conditions. As a concrete example, we show that wavenumber 1 and 2 disturbances in the continuous spectrum develop a nonlinear evolution for realistic polar-night stratospheric-jet configurations. Numerical simulations of a perturbed polar vortex are presented to illustrate the linear and nonlinear wave dynamics for this class of swirl profiles and the results are compared to atmospheric observations.

EROSION OF A DISTRIBUTED VORTEX BY A GROWING SHEAR

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We present a theoretical study of the process of vortex erosion under a growing uniform strain flow which is relevant to many geophysical situations. The vortex is deformed and progressively torn apart into thin filaments expelled in the embedded fluid. The steepness of this process is clearly influenced by the vorticity profile and by the straining rate. We first discuss the particular case of a uniform vortex and compare it with the erosion of a distributed vortex which is treated analytically within the approximation of the elliptical model. The role of the filaments during the final breaking is exhibited by a comparison with contour dynamics. By adding a viscous dissipation, even in the case of a constant subcritical strain, the erosion occurs through a diffusive flux across the separatrice and by enhanced internal decay until the vortex reaches the breaking point. This effect can be cast within the simple framework of the elliptical model. This theory is compared to numerical experiments.

TRIPOLAR VORTICES IN STRATIFIED GEOSTROPHIC FLOWS

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We investigate the formation of baroclinic tripoles in stratified geostrophic flows. Isolated, circular and surface-intensified vortices can be prone to both barotropic and baroclinic instabilities, depending on their potential vorticity distribution, which can be continuous or piecewise-constant. For strong instabilities, vortex breaking produces either horizontal or vertical dipoles, whereas for weaker instabilities, various stationary baroclinic tripoles are formed, surface-intensified or arch-shaped. Rotating steady states are then searched both for the piecewise-constant vorticity tripoles (by iterative methods) and for the continuous vorticity tripoles (by vorticity-streamfunction scatter plots). Finally, the stability of these baroclinic tripoles is tested by displacing the satellites: these vortices are indeed robust. On the beta-plane however, the permanent anisotropy forced by the planetary vorticity on the tripole results in asymmetric breaking and in the disappearance of both satellites. We also show that baroclinic tripoles can result from the alignment of asymmetric hetons; these steady tripoles form a third type which is not surface-intensified, nor arch-shaped. Baroclinic tripoles therefore seem to be important new vortex structures of which more examples should be searched in geophysical flows.

SYSTEMATIC DRIFT EXPERIENCED BY A POINT VORTEX IN 2D TURBULENCE

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Using a linear response theory, we show that a point vortex in 2D turbulence experiences a systematic drift normal to its mean field velocity. Taking this result into account, we derive a Fokker-Planck equation for the time evolution of its distribution function and make the link with a Maximum Entropy Production Principle. Owing to the fluctuation-dissipation theorem (and via an Einstein-like formula), this approach allows us to determine explicitely the value of the diffusion coefficient (which is not given by the M.E.P.P). We also discuss the analogy with stellar systems: in particular, the *systematic drift* of the vortex is the counterpart of the *dynamical friction* experienced by a star due to close encounters.

Upscale energy transfer in quasi-two-dimensional turbulence with bottom friction

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We present results of numerical integration of quasi-2D turbulence in a 2D-flow with bottom friction. As is well-known, bottom friction introduces a limiting scale at which the inverse transfer of energy is arrested. This scale is a function of the Reynolds number Re_λ based on the bottom friction. We analyse energy spectra and show that this limiting scale behaves like Re_λ^α, where $\alpha \approx 0.4$. Upscale energy cascade rate is not constant in the energy range since bottom friction dissipates all scales equally. Nevertheless the spectral slope of energy is close to -5/3 as one would expect in the case of constant energy transfer rate. The presence of bottom friction at all scales also leads to low values of kurtosis of vorticity field. It is close to a value of 3 characteristic of a random Gaussian field.

Lateral spreading of strip-shaped convective region as derived from a two-layer heton model

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A 2-layer model of singular geostrophic vortices is applied to simulate the spreading stage of deep ocean convection for a strip-shaped convecting chimney. We investigate the equilibration of potential density anomaly within the convecting area. The potential density anomaly and the equilibration time are found to obey simple scalings suggested by Legg *et. al., J. Phys. Oceanogr.*, **26**, 2251–2266, (1996). The proportionality factor in the parameterization of lateral fluxes of potential density turns out to be sensitive to the geometry of the region and the layer structure. The horizontal spreading of the potential density anomaly shows quasi-linear dependence on time at moderate values of surface buoyancy flux. This behavior can be attributed to the formation of heton clusters that move out of the cooling area. The linear stability problem is analyzed for a homogeneous two-layer heton-like strip of potential vorticity anomaly. It predicts the scale of most unstable wave as a function of layer thicknesses and gives an estimate for the linear instability time for the time-dependent basic flow.

NP5

DYNAMICS OF POINT-VORTEX STRUCTURES IN A TIME-DEPENDENT COASTAL (RIVER) 2D-FLOW

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We discuss the influence of a time-dependent flow on the behaviour of vortex structures in a river channel. Several aspects of a similar problem have been studied by Goncharov and Pavlov (1997, *Ann. Geophys.*, **15**, Sup II, C597): the vortex pairs behaviour in the presence of a source of constant potency located at rivers mouth has been discussed. Here, we focus on the influence of a flow variation in time, on the configuration of such vortex structures, in particular on the localization of stagnation domains. In order to illustrate qualitatively the problem, we consider the case where the vortex structures can be approximated by quasi-ponctual vortices. It is shown that in the case of a time-dependent river flow, the conditions for existence of stationary vortices can change drastically.

SALMON'S HAMILTONIAN APPROACH TO BALANCED FLOW APPLIED TO A ONE-LAYER ISENTROPIC MODEL ON A SPHERE

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We will discuss a hydrostatic atmospheric model, consisting of a single layer of constant potential temperature. Orography is included, forcing and friction are absent and the geometry is a rotating sphere. The system is governed by an equation for the conservation of horizontal momentum and an equation for the conservation of mass, and is closely analogous to a one-layer shallow-water system. Balanced flow is defined by $M' = f\psi$, where M' is the deviation of the Montgomery potential from the value corresponding to the state of rest, f is the Coriolis parameter and ψ is the streamfunction that defines the balanced velocity field $\mathbf{v}_b = \mathbf{k} \times \nabla\psi$. Salmon's Hamiltonian technique is applied to find an approximation to the horizontal momentum equation that retains a proper equivalent of potential vorticity conservation and conservation of total energy. When the approximated momentum equation is combined with the original mass conservation equation, an equation for the unbalanced 'ageostrophic' velocity field $\mathbf{v}_a$ can be found. It is shown how the latter equation can be solved and how the system can be integrated in time by materially advecting potential vorticity with the total velocity $\mathbf{v}_b + \mathbf{v}_a$.

TRAJECTORIES OF VORTICES EMITTED INTO RIVER MOUTH

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We consider the dynamics of strong, localized vorticity concentrations in a flow. We study the dynamics of point vortex systems with boundary conditions. Results of analysing dynamics of vortex dipoles in rivers mouths are presented. Main purpose is construction of the possible scenarios, their classification and definition of geophysical parameters for really observable phenomenon of emitting dipole vortex structures from river mouths into open ocean. If the river inflow is simulated by a point source of constant potency, the considered process will be realized only in narrow mouths with half-angle less than $\pi/4$. Two topologically various kinds of motion trajectories are possible for the vortex dipoles outgoing from a source. If the their energy is more than defined threshold value, the vortices move along open trajectories and abandon the river mouth. Otherwise the vortices move along closed trajectories without escaping from the river mouth.

A 3-D HETON MECHANISM OF LATERAL SPREADING IN A STRATIFIED ROTATING FLUID

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The physical mechanism of lateral spreading of buoyancy from a localized convective region in a continuously stratified rotating fluid due to localized baroclinic vortices (3D hetons) is considered. A 3D heton is viewed as an elementary block to construct distributions of PV generated by buoyancy forcing. Based on the PV evolution equation in the quasigeostrophic approximation, we derive equations describing the motion of a population of 3D hetons. We investigate in detail the interaction between two hetons and show that the vortices can be in confinement, splitting or reconnection regimes of motion. Numerical experiments made for ring-like populations of randomly distributed 3D hetons show that mean radius of heton population and its variance grow linearly with time. As applied to the problem of vorticity and passive scalar transport this law implies hyperdiffusion. It essentially differs from the ordinary square-root diffusion law. Linear law of spreading for the mean radius of heton populations implies that commonly used diffusion-like parameterizations of lateral buoyancy transport are questionable, at least under conditions when splitting regime of heton dynamics dominates.

HAMILTON'S PRINCIPLE FOR QUASIGEOSTROPHIC MOTION

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We show that the equation of quasigeostrophic (QG) potential vorticity conservation in geophysical fluid dynamics follows from Hamilton's principle for stationary variations of an action for geodesic motion in the f- plane case or its prolongation in the β - plane case. This implies a new momentum equation and an associated Kelvin circulation theorem for QG motion. We treat the barotropic and two-layer baroclinic cases, as well as the continuously stratified case.

TRIADIC INTERACTION OF OBSERVED ATMOSPHERIC BLOCKING- AND CYCLONIC-SCALE VORTICES IN THE ORTHONORMAL WAVELET REPRESENTATION

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Traditionally the nonlinear transfer of kinetic energy between orthogonal modes in fluid dynamics has been described by a kind of convolution of Fourier coefficients, known as 'triad interaction'. Triad interaction between wavenumbers n, $-m$ and $m-n$ is known to be constrained by a 'detailed conservation' theorem. Recently Iima and Toh have generalized this description, in the case of incompressible flow, from Fourier to arbitrary orthogonal decompositions.
This presentation will show the empirical results of computing triad interactions between orthonormal wavelet modes, which describe localized vortices such as atmospheric blocks and cyclonic-scale eddies much more efficiently than Fourier. Hypotheses regarding the eddy forcing of blocks are formulated, based on the relative horizontal phase shift (tilt) of eddy streamfunction structures overlying the larger blocking streamfunction pattern. These hypotheses are checked case-by-case for NMC analyses of observations of different flow synoptic states.

FORCED DIVERGENT ANTICYCLONES AND THE MONSOON VORTEX

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We shall describe the properties of the anticyclonic vortex forced in an almost-inviscid shallow-water model by a localized "thermal" forcing (mass relaxation). On the f-plane, the response is a circular anticyclone of almost zero absolute vorticity, in agreement with inviscid axisymmetric theory. When a β-effect is introduced, the vortex is distorted by becoming elongated toward the west, but otherwise not greatly changed, as long as $\beta L^2/U_\chi < 1$, where L is a scale for the vortex size and U_χ the magnitude of the forced divergent flow. However, if $\beta L^2/U_\chi > 1$ the forced vortex periodically sheds anticyclonic eddies which propagate away to the west, and its absolute vorticity is no longer close to zero. For the most part, these results have straightforward dynamical interpretation. The importance of the parameter $\beta L^2/U_\chi$ can be seen as a ratio of the free drift speed of the vortex to the strength of the divergent flow that is maintaining its position. The change of the vorticity between the two regimes can be predicted, through an extension of earlier arguments concerning the vorticity budget, to be associated with the increased effective friction accompanying vortex shedding. Global meteorological analyses appear to reveal subtropical, upper tropospheric anticyclones being shed in a similar way from the Tibetan high.

KÁRMÁN VORTEX STREETS AS STABLE ATTRACTORS OF FORCED-DISSIPATED FLOWS

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Unidirectional shearing, 2D flows are often embedded with Kármán vortex streets (*n.b.* almost all Jovian vortices are in streets). When the flow is forced and dissipated, the streets are stable, attracting, dynamical equilibria. (In contrast, a single row of vortices is unstable.) Jovian vortices are forced by merger with smaller vortices, and we model this forcing with finite amplitude perturbations to steady vortex patches. Dissipation occurs primarily when vortices collide with stagnation points and eject thin filaments which are dissipated by molecular viscosity. In our model, these filaments are cut from the contours when they are sufficiently distant from the shedding vortex patch. The dynamics of the filamentation and therefore the evolution towards attractors is controlled by the pattern and proximity of stagnation points in the street. There are three possible topologies of particle paths connecting stagnation points (homoclinic and heteroclinic orbits). We demonstrate the progression towards attractors in this system, and find that one particular topology appears to be the attracting structure for all streets. We compare with planetary observations.

A DIRECT EXAMPLE OF WAVE-VORTEX INTERACTION IN ROTATING SHALLOW WATER

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Using a physical space (i.e. non-modal) approach, we investigate interactions between fast inertia-gravity waves and slow balanced flows in a shallow, rotating fluid. Specifically, we consider a train of gravity waves impinging on a balanced vortex. For simplicity, we study the one-dimensional problem first; the limitations of one-dimensionality are offset by the ability to define balance in an exact way. We perform an asymptotic analysis of the problem in the small amplitude limit to demonstrate the existence of interactions. We show these interactions are not confined to the modification of the wave field by the vortex but, more importantly, that the waves are able to alter in a non-trivial way the potential vorticity associated with the vortex. Interestingly, owing to the restrictions of one-dimensionality, the net interaction is nil in the sense that once the waves have traversed the vortex region and have propagated away the vortex exactly recovers its initial shape (no net energy transfer). Furthermore, we prove the last result in the case of *arbitrary* vortex and wave amplitudes. Numerical integrations of the full one-dimensional shallow water equations in strongly nonlinear regimes are also performed; they confirm that time-dependent interactions exist and increase with wave amplitude while the final state of the vortex bears no sign of the interaction. Finally, we discuss the extent to which these results hold in a more realistic two-dimensional problem.

STABILITY OF LARGE-SCALE VORTICES: FROM SHALLOW-WATER TO FRONTAL DYNAMICS

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We discuss linear and nonlinear stability properties of axisymmetric isolated vortices in a hierarchy of balanced models resulting from the rotating shallow-water equations on the f-plane, namely, quasi-geostrophic, intermediate geostrophic and frontal dynamics models. In nonlinear stability studies we use the Hamiltonian approach and the energy-Casimir method in order to get sufficient conditions for stability. In particular, we show that in the frontal dynamics regime both cyclonic and anticyclonic vortices with monotonous elevation profile are nonlinearly stable.

HYPERBOLIC INSTABILITY IN ROTATING DIPOLES

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The geometrical optics stability theory for short-wave instabilities [Lifschitz & Hameiri, Phys. Fluids A **3**, 2644 (1991)] is used to show that any steady inviscid plane flow subjected (or not) to a Coriolis force with perpendicular angular velocity vector is unstable to three-dimensional perturbations if $\Phi(\mathbf{x}_0) < 0$ on a stagnation point located at $\mathbf{x}_0$. Φ is the second invariant of the inertial tensor [Leblanc & Cambon, Phys. Fluids **9**, 1307 (1997)]. In particular, at zero tilting vorticity $\mathbf{W}(\mathbf{x}_0) + 4\boldsymbol{\Omega} = 0$, any stagnation point (hyperbolic, elliptical or pure-shear) is unstable. On the other hand, any vortex core (elliptical or circular) is stable at zero absolute vorticity $\mathbf{W}(\mathbf{x}_0) + 2\boldsymbol{\Omega} = 0$. The criterion is applied to Chaplygin's non-symmetric dipolar vortex moving along a circular path [Meleshko & van Heijst, J. Fluid Mech. **223**, 1 (1991)] which is shown to be unstable, owing to the hyperbolic stagnation points located on the boundary of the dipole [Leblanc, Phys. Fluids **9**, 3566 (1997)].

NP5

BEACH VORTICES

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A variational characterisation of steadily propagating vortices over uneven topography is presented. This is used to prove the existence of and construct solutions for vortices propagating along sloping beaches. Particular examples of vorticity distributions and beach profiles are discussed and formulae given for the shape and speed of the vortices.

NON-LOCAL 2D TURBULENCE: A TWO FLUID APPROACH.

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High-resolution DNS of forced 2D turbulence by Borue (1993) indicate that 2D turbulence is non-local: "the primary contribution to the enstrophy transfer function comes from wavenumber triads with one small leg and two long ones". We use this fact to develop a two-fluid model, in which the fluid flow is divided into the large-scale and small-scale components evolving acoording to their own (coupled) equations which are averaged over the small scale. These model is rigorously derived from the Navier-Stokes equations under the assumption of non-locality in small-scales and does not contain any adjustable parameters. The small-scale equation has a WKB form for turbulence wave-packets which are advected by the large-scale flow and the wavenumber of which is evolving due to the large-scale shear/strain. These wave-packets contribute into the the large-scale equation via the averaged Reynolds stresses, so that the total energy and enstrophy of the large and small scales are conserved. We developed a new numerical method based on the two-fluid model suitable for high-Reynolds number LES of 2D flow. We discuss our numerical and analytical results, such as the spectral exponents for the small-scale turbulence and passive scalars and PDFs. Comparison with high-resolution DNS shows that the two-fluid method performs remarkably well for very high Reynolds numbers.

BALANCED MODELS. PART I: THEORY

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Balanced models provide a simplified description of the motion of reduced dimensionality in a parent model. They describe the balanced motion in a parent model which allows both balanced motion (resulting from balance between forces or slaving from fast modes to slow modes) and unbalanced motion (spontaneous radiation of fast modes). We discuss the analogy between the shallow-water and the Euler-Boussinesq parent model, which relates a vorticity gradient in a horizontal layer to a density gradient in a vertical slice, Rossby waves and surface gravity waves to internal gravity waves and acoustic waves, and geostrophic to hydrostatic balance.
Balanced models are defined by balance dynamics (prognostic equations for the slow modes), and balance conditions (diagnostic equations for the fast modes) that determine the constraint manifold. The relation to the (quasi-) slow manifold, centre manifold, (approximate) inertial manifold, and (strange) attractor is discussed. An overview of various choices for balanced models is presented: parent model, slaving variable (relative vorticity, geopotential, potential vorticity), decomposition of velocity field (geostrophic-ageostrophic, vorticity-divergence, slow-fast), and formal expansion scheme (based on momentum or vorticity-divergence equations, normal mode decomposition, Hamiltonian variational principle, or semi-geostrophy).
There are fundamental limitations to the concept of balance: the small parameter is not given explicitly but follows from scaling analysis; scale separation is not strict in the presence of linear dispersive waves; invertibility is violated for intense vortices and near the equator; spontaneous emission of fast modes provides unbalanced motion; and interactions of unbalanced motion may exist. These are discussed, as well as the the relation between stability problems and balance problems: linear instability is related to secular terms and breakdown of formal expansions in all parameters; and inertial instability is related to non-ellipticity of the equations and breakdown of invertibility. See DAMTP homepage http://www.atm.damtp.cam.ac.uk/people/ecn20

BALANCED MODELS. PART II: NUMERICS

E.C. Neven (Atmospheric Dynamics Group, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, United Kingdom)

Balanced models in the context of a parent shallow-water model on a rotating hemisphere are presented. The balance conditions are based on decomposition of the velocity field either into vorticity and divergence components (as in the linear and Charney balance models, and in the direct inversion models), or into slow and fast modes (as in the slow equation models, and in the linear, Machenhauer and Baer-Tribbia normal mode inversion models). The balance dynamics are local vorticity conservation, local mass conservation or material potential vorticity conservation, and the corresponding slaving variables are relative vorticity, geopotential or potential vorticity, respectively. Through a formal expansion in terms of Rossby number as the small parameter, hierarchies of balanced models are constructed with increasing order of accuracy. As a measure of accuracy of the balanced model with respect to the parent shallow-water model, either instantaneous or cumulative root-mean-square error of divergence or geopotential field is used.
Through numerical time integrations with a high-resolution spectral code the balanced models are compared with the shallow-water model. This extends the work by McIntyre and Norton (1997). The balanced model runs are much more expensive than the shallow-water runs due to the many nonlinear terms, iterations and relaxations required to solve the nonlinear balance conditions. The accuracy is determined near the equator to test the validity for large local Rossby numbers, and for small equivalent depth to test the validity for local Froude numbers not far short of unity. For potential vorticity balanced models, local mass (non)conservation is discussed.
This is part of SWEEP, a comprehensive research programme on coherent structures, balanced models, and topology and geometry of flow domain manifolds, in the fields of atmospheric science, fluid dynamics, plasma dynamics, nonlinear science and theoretical physics. See DAMTP homepage: http://www.atm.damtp.cam.ac.uk/people/ecn20

THE BREAKING OF ROSSBY WAVES AT THE BOTTOM OF THE STRATOSPHERIC POLAR VORTEX

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Using a multilayer quasigeostrophic model, we investigate the response of an idealized baroclinic polar vortex to topographically forced Rossby waves. We consider a number of initial potential vorticity configurations, and describe under which circumstances the wave breaking is confined to the bottom part of the vortex. In contrast to the findings of Dritschel & Saravanan (*Q.J.R.M.S.*,120, 1994) for a barotropic vortex, we show that low-level wave breaking can occur even at small forcing amplitudes. We construct a kinematic interpretation of this behavior in terms of the distance between the polar vortex edge and the stagnation points of the flow. We discuss the relevance of these results to the maintenance of stratopsheric polar "sub-vortex".

THREE-DIMENSIONAL INSTABILITIES OF COLUMNAR VORTICES ON THE *F*-PLANE

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We consider the stability of columnar vortices against three-dimensional perturbations in the presense of background rotation and as a function of the ellipticity of the vortex. As a model of the basic vorticity distribution, we employ the Stuart (1967) steady solution to the Euler equation. In the case of rotating flow, an anticyclonic vortex is shown to be unstable for small values of the background rotation, while fast rotation strongly stabilizes both anticyclonic and cyclonic columns, as expected on the basis of the Taylor-Proudman theorem. We demonstrate that there exist three distinct forms of three-dimensional instability to which strong anticyclonic vortices are subject. One form of instability consists of a Coriolis force modified form of the elliptical instability, which is dominant for vortex columns whose cross sectors are strongly elliptical in the case of the Stuart model of the basic state. The second form of instability may be understood to constitute a three-dimensional inertial (centrifugal) instability, which became the dominant mechanism of instability as the ellipticity of the vortex column decreases. Also evident in the Stuart model of the vorticity distribution is a third "hyperbolic" mode of instability that is focused on the stagnation point that exists between adjacent vortex cores.

NUMERICAL SIMULATION OF NONLINEAR INSTABILTIES OF COUNTER-ROTATING VORTEX PAIRS IN STRATIFIED AND UNSTRATIFIED FLUID

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Nonlinear instabilities of counter-rotating vortex pairs in stratified and unstratified fluid are studied by means of numerical solutions to the governing equations. Each vortex is initialized as a superposition over a spectrum of wavelengths of slightly perturbed component vortices with randomly selected phases. The cross-axial vorticity distribution of the component vortices is Gaussian, with a core radius, r, equal to 0.16 of b, the separation of the vortices. Numerical results are shown for Froude numbers (Fr) infinity, 8, 4, 2 and 1, where Fr = V/Nb, N being the Brunt-Vaisala frequency of the fluid, and V being the initial descent speed of the vortices. In unstratified fluid, the vortices develop a slowly growing small scale instability of axial wavelength on the order of b which is eventually dominated by the growth of a large scale (Crow) instability with axial wavelength on the order of 8b. As the Crow instability continues to grow, the vortices link, and vertically migrating rings are formed. For low to moderate stratification of the fluid (Fr $\geq$ 4), increasing stratification accelerates the growth of the Crow instability, but if the stratification is increased until the buoyancy time scale is of the same order as the linking time scale (Fr = 2), then ring formation is suppressed, and axial density gradients cause the formation of puff-like structures instead of rings. As stratification is further increased (Fr = 1), buoyancy effects prevent growth of the Crow instability, and growth of the small scale instability is accelerated. Numerical results show good agreement with laboratory observations of the small scale instability for Fr = infinity and 1. The vortex Reynolds number, Re = Γ/ν, for the simulations is either 1500, for comparisons with laboratory observations, or 3000.

ON THE ERTEL AND IMPERMEABILITY THEOREMS FOR SLIGHTLY VISCOUS CURRENTS, WITH OCEANOGRAPHIC APPLICATIONS.

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We analyse theoretically how a mild fluid viscosity can effect the potential vorticity for stratified fluids in a rotating system. A generalization of the classical Ertel theorem will be discussed and the law of conservation corresponding to novel invariants Π is obtained. These invariants do not have a classical form: indeed one example is mere classical potential vorticity multiplied by a time function. It has to be stressed that similar relations hold for a large class of conserved quantities, such as tracers, entropy, etc. Our results are also compared with those deriving from the recent Impermeability theorem by Haynes and McIntyre, a comparison that gives some new insight into stratified fluid dynamics. Among other results we obtain an effective way of estimating the importance of frictional effects on the potential vorticity evolution along streamlines and a generalization of the classical "thermal wind" relation. These ideas are then applied to various cases of oceanographic interest, such as equatorial currents, small space-scale motions, thermocline ventilation relative to various tracers, as well as to steady or quasi-steady fronts and cold filaments, namely the long patches that are often observed in thermal satellite images.

Coastal current bifurcations due to topography: sensitivity to variations of the vorticity profile of the coastal current.

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Models of the effect of along-shore variation of topography on coastal currents using barotropically stable coastal currents have been succesful in predicting current bifurcations, but have not reproduced all of the variability typically observed in laboratory experiments and ocean observartions. One source of the observed variability is barotropic instability of the coastal and off-shore currents. Another source is eddy generation due to the interaction of the topography with complex coastal current profiles. Simulations based on barotropic quasi-geostrophic dynamics are performed to help determine the nature of the observed variability. A variety of profiles are tested and the resulting flows are compared.

Experiments on the bifurcation of a coastal current in presence of a topographic slope

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The purpose of these experiments is to reproduce in a rotating system the dynamics of a current flowing along the coast and in presence of a step-like bottom slope perpendicular to the coastline. The experiments were performed in a rotating tank of 1 m × 1.5 m. In the middle of the longer side, a narrow slope (4 cm wide) was fixed with the topographic contours perpendicular to the coastline. The current was created by a local source flowing parallel to one of the walls. Two different types of experiments were performed, depending on the initial position of the source: coastal currents (flowing with the wall to the right) from deep to shallow waters and vice versa. The water level (24 cm) was maintained constant by using a sink in the opposite side of the tank. When the current flows from deep to shallow waters, it bifurcates following the depth contours, perpendicular to the coast (a similar effect is observed in the Adriatic sea). For currents flowing from shallow to deep waters, part of the current turns off-shore forming a dipole structure, while the other part crosses the slope and continues along the coast. These results are in good agreement with quasi-geostrophic finite-differences direct simulations and with an analytical model.

INTERACTIONS BETWEEN FINITE-CORE HETONS

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Heton concept introduced by Hogg and Stommel (1985) is believed to be a relevant prototype of oceanic baroclinic vortices and especially of Gulf Stream rings. Valcke and Verron (1993) gave a first classification of the possible interactions between mutually compensated two-layer vortices (hetons) depending on the values of the internal radius of deformation, the initial distance between hetons and the radius of the potential vorticity patches. Their numerical results, obtained using a finite-difference code, show that the parameter space consists of three main sub-domains corresponding to distinct behaviors: 1) divergence of the hetons ("heton regime"), 2) coupling of the same-layer vortices with merging, 3) coupling of the same-layer vortices without merging.
In the present work, a more extensive study of the heton interactions has been conducted using the contour dynamics method (CDM). Main behaviors coincidate for both models but the CDM study brings more detailed view of the complicated "heton regime" which subdivides into four subclasses: 1a) divergence with initial merging, 1b) divergence without merging, 1c) decay which brings smaller-scale heton formation and their further scattering, 1d) decay resulting in formation of non-compensated two-layer vortices which sequentially, merge, then disintegrate into hetons of smaller scale, and scatter. This work is supported by INTAS (Grant N^0 94-3614).

NUMERICAL INVESTIGATION ON THE STABILITY OF ISOLATED VORTICES BEYOND THE QUASI-GEOSTROPHIC DESCRIPTION

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The stability of a family of circular and isolated vortex is studied numerically using the Contour-Advective Semi-Lagrangian (CASL) algorithm [1].The full shallow-water equations are solved and therefore the instability mechanism can be investigated in a wide range of parameters. The steepness of the vorticity profile is used as a critical parameter. Both large-scale and ageostrophic effects are shown to stabilize isolated vortices. The anticyclones tends to be favoured in this restabilization process. Comparison with the standard Quasi-Geostrophic description will be presented.

References

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VORTICES IN THE ENSTROPHY INERTIAL RANGE:A PHENOMENOLOGICAL THEORY

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The properties of vortices in a strain field are used to construct a phenomenological theory of the enstrophy inertial range in two-dimensional incompressible turbulence. The theory, based in part on the results and behavior of numerical simulations, combines spectral inertial range theories of the Kolmogorov type with the dynamics of vortex interactions in physical space. It is based on the assumptions that coherent vortices can survive in a turbulent flow if of sufficient strength compared to the background straining field, and that coherent structures feel a mean strain field, independent of their scale. The first assumption is suggested by a result in the theory of uniform elliptic vortices, while the second comes from numerical simulations. The theory predicts that at small scales in forced-dissipative two-dimensional turbulence the energy spectrum will obey the classical enstrophy inertial range predictions even though the nonlinear interactions remain spectrally non-local. Passive scalar dynamics at all scales are predicted to be similar to vortex dynamics at small scales. Available numerical simulations are consistent with these suggestions.

NP5

INTERACTION BETWEEN A COHERENT EDDY AND A THIN ZONAL OCEAN JET USING A TWO-AND-A-HALF-LAYER QUASI-GEOSTROPHIC MODEL

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In the Azores-Madeira region, recent sea measurement cruises have revealed the existence of interactions between subsurface anticyclonic eddies (of the meddy type) with the Azores stream. In this configuration, the eddy undergoes advection by the average stream and self propagation by the beta effect. Another mechanism based on the mutual influence of the vorticity of both meddy and of a field of sheared velocity, leads to the propagation of the eddy. The zonal stream (West-East) is subjected, in return, to strong deformations in the presence of eddies : meanders are created on the jet.
In this study, we examine the nonlinear interactions between a zonal jet and a vortex, using a two-and-a-half-layer quasi-geostrophic numerical model. The eastward jet in layer one is defined by two strips of constant and opposite potential vorticity. The anticyclonic eddy in layer two is initialized north of the jet by a circular patch of constant potential vorticity. We numerically determine the physical conditions under which the eddy crosses the jet meridionally, or drifts along its northern side. Furthermore, an analytical criterion for the crossing of the jet is established, which remarkably compares with the numerical experiments. The sensitivity of these dynamic regimes to environmental parameters is finally examined.

EVOLUTION OF A LAMB QUADRUPOLAR VORTEX

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Lamb vortices are stationary solutions of the Euler equations in two dimensions. They are formed by a circular core, divided in an even number of sectors of vorticity of alternating sign, and an exterior potential flow. The well-known Lamb dipolar vortex is the simplest of these structures, and the quadrupolar vortex follows in increasing order of complexity: The interior flow is divided in four sectors where the vorticity has alternating sign, and the exterior flow is a linear strain field. This quadrupolar vortex is perturbed and its evolution is studied numerically. The perturbations prescribed are: (a) an elliptical deformation of the vortex, (b) a shift of two oppositely-signed sectors, and (c) a rotation of the vortex with respect to the strain axes. It is found that the vortex is stable to elliptical deformations provided that the axes of the ellipse are parallel to the axes of the strain flow, in which case the vortex pulsates quasi-periodically. Shifting two sectors leads to vortex translation or destruction, depending on whether the shift is made towards the unstable or stable directions of the strain, respectively. Finally, when the quadrupolar vortex is rotated with respect to the strain axes, two sectors of equally-signed vorticity merge to form an elongated vortex, while the other two sectors are stretched and reduced to thin filaments along the strain's unstable direction.

ON THE PROBLEM OF A CURRENT'S PERIODICAL STRUCTURE IN THE VICINITY OF SEAMOUNTS IN A TIDAL SEA

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In a frame of the nonviscous quasi-geostrophic model (NVQG-model) of a homogeneous ocean on a f-plane the dynamics of topographic and carried eddies in a vicinity of an isolated seamount in a tidal sea are investigated by the Contour Dynamics Method. The following cases are examined: a) the pure oscillatory tidal current with degraded tidal ellipse; b) the tidal current with nondegraded ellipse; c) the tidal current with a background component. It was shown that the carried eddy evolution has nonturning nature. The instability of the second mode plays the determining part in its dynamics that leads to a decay of the carried eddy on two parts. Therefore it is impossible to obtain the periodical vortex structure in a frame of NVQG-model. The viscous QG-model is examined.

The research was supported by Grant INTAS (No.94-3614).

VORTEX MERGING IN QUASIGEOSTROPHIC FLOWS: A LAGRANGIAN VIEW

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We study the merging of same-sign vortices in baroclinic, quasi-geostrophic flows. We discuss the dependence of the merging process on the aspect ratio of the merging eddies and on the type of vertical boundary conditions.
A Lagrangian picture of the merging process is provided by the time evolution of the distribution of a large number of passively advected particles.

STAAARTE STAARTE Workshop

Convener: Krautstrunk, M.

ATMOSPHERIC FIELD STUDY IN THE LISBON REGION

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In order to study mesoscale atmospheric systems and to be able to describe air pollutants dispersion patterns it is necessary to obtain a more detailed characteriza-tion than the available through regular networks. As a result of this concern a meteorological campaign was conducted between July 8th and 18th 1997 in the region of Lisbon. Lisbon, with a total population of 3.5 million inhabitants is built in a very complex topographic region, dominated by a 320 km² large estuary and multiple hills, surrounded by small mountain ranges reaching heights over 400 m above sea level. A surface network including meteorological and air quality measurements was in continuous operation during the period of the campaign. The field campaign was organized in conjunction with the STAAARTE program. Under STAAARTE, four ARAT flights were performed. The main objective of the flights was to track the mass of pollutants emitted in the central part of Lisbon and follow the transport patterns. Special interest was concentrated in the collection of experimental data to describe the sea breeze front penetration and the formation of an ozone plume over the Tejo estuary.
This paper includes a thorough description of the field campaign structure , as well as a presentation of the main conclusions of this project.

CHARACTERIZATION OF TROPOSPHERIC AEROSOLS IN THE EASTERN MEDITERRANEAN FROM AIRBORNE AND OTHER MEASUREMENTS DURING THE JUNE 1997 STAAARTE CAMPAIGN.

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We present results on the composition, size distribution, vertical and horizontal distribution of tropospheric aerosol particles from airborne measurements performed in the eastern Mediterranean during the June 1997 campaign of the European TMR Programme STAAARTE, and from accompanying measurements made in the frame of the European Environment and Climate Programme MEDUSE. On June 7 and 10, we flew aboard the DLR research FALCON 20 between continental Greece and Crete. Airborne instrumentation included optical systems for in-situ particle sizing, meteorological and radiation measurements. The downward viewing lidar system ALEX was used on June 7. On June 10, instead of ALEX we tested an electronically controlled isokinetic probe for aerosol sampling (cf contribution by Filippi and Le Roulley) and an aethalometer for aerosol absorption measurement and carbonaceous aerosol sampling. Additional airborne aerosol sampling by impaction on membrane filters was done for laboratory microscopic investigations. Additional accompanying measurements included ground-based aerosol measurements of aerosol concentration, composition and optical depth on the northern coast of Crete, and Meteosat and AVHRR aerosol remote sensing. We combine available results to characterize two frequent cases of large-scale high aerosol load in the eastern Mediterranean: (i) the presence of a residual dust layer over the marine boundary layer associated with a recent African dust transport event (June 7), and a highly polluted marine boundary layer (June 10).

Abstract: STAAARTE AND THE MRF C-130 RESEARCH AIRCRAFT

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The MRF C-130 aircraft has been selected by EU as a Large Scale Facility (LSF), along with the French ARAT Fokker 27 and German Falcon 20 aircraft. It is available for research by European scientists under the TMR/LSF programme STAAARTE (Scientific Training and Access to Aircraft for Atmospheric Research Throughout Europe). Scientific user groups interested but inexperienced in gathering meteorological data from aircraft can request access through STAAARTE. An independant Allocation Committee will select suitable proposals to be flown. Thereafter, a facilitator at the LSF will guide the user through the whole campaign.

The C-130 aircraft carries a very wide range of instrumentation to support the research undertaken for these selected user groups. The following can be measured:

(a) Aircraft position, speed and attitude
(b) Atmospheric structure and turbulence
(c) Atmospheric radiation
(d) Cloud Physics properties
(e) Aerosol properties
(f) Atmospheric composition
(g) Surface properties.

The collection of data is automated and the scientists on board can see the measurements displayed in real time in a graphical form. This allows good planning of the flights to be made and ensures the mission objectives are met. Data processing begins as soon as the aircraft lands, so that calibrated data are normally available to scientists soon after the flight. The talk will illustrate the aircraft's capabilities.

Coastal Boundary Layers in the Baltic Sea

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The adjustment of the flow in coastal areas, going from land to sea is quite drastic, the roughness length decreases by several orders of magnitude and the atmospheric stability changes significantly. The rate of this adjustment of mean flow and turbulence to a new set of equilbrium values is very much dependent on stability, where especially stable conditions are interesting because the suppression of turbulence associated with stable layers, prolongs the adjustment of the coastal internal boundary layers and additionally can cause phenomena like low-level jets.
These coastal boundary layers were investigated in the VCAP campaign flown around the Swedish island of Gotland. Vertical profiles gave information about the general structure of the boundary layer, straight and level flights perpendicular to the coast reveals the extent of the internal boundary layers offshore and flights along the coast tell us about the horizontal homogeneity of the flow. The VCAP campaign took place during conditions of predominantly stable conditions over the Baltic Sea. Initial analysis of flight data are shown together with simultaneous fixed platform measurements off the East coast of Gotland.

Abstract: STAAARTE AND THE MRF C-130 RESEARCH AIRCRAFT

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USE OF C-130 AIRBORNE MEASUREMENTS IN THE VERIFICATION OF SATELLITE ALBEDO MEASUREMENTS IN THE NORTHERN NOPEX/WINTEX AREA

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In the context of WINTEX programme, airborne measurements in Sodankylä, northern Finland, were conducted in March 1997. WINTEX is an acronym for a project aiming at the planning of a future, full-scale winter-time Concentrated Field Effort (CFE) within EU-funded NOPEX programme, the aim of which is to study land-surface processes at a regional scale for a mixed land cover dominated by boreal forest. The airborne measurements were accomplished with the support of European Union's STAAARTE programme. The flights were performed with a Lockheed C-130 Hercules aircraft operated by the Meteorological Research Flight of the UK Meteorological Office in Farnborough, United Kingdom.

In this study, an analysis of ground albedo based on airborne measurements is presented. Albedo is strongly dependent on the ground properties, and especially snow cover can have a drastic effect on it. To properly account for albedo is very important in climatic and weather forecast models. Albedo is usually approximated using satellite images. A significant problem is how to account for the effects of atmosphere as well as small scale spatial changes in albedo. Close-to-ground measurements from aircraft are an important means to calibrate the methods for satellite-based albedo estimates. In the analysis, aircraft-based albedo has been compared with values obtained from satellite images.

The measurement flights were supported by the European Community Programme for the Training and Mobility of Researchers.

DLR FALCON: A RESEARCH AIRCRAFT AS MULTISENSOR PLATFORM

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DLR Falcon 20 E, D-CMET, has been selected by EU as large scale facility (LSF). This twin jet propulsion aircraft well experienced in tropospheric and stratospheric research flights is available for European scientists within the EU-TMR program: STAAARTE. Scientists interested but unexperienced in meteorological chemical or remote sensing data from aircraft measurements can ask for aircraft access. Once selected, they will get the opportunity either to choose their own individual sensor package neccessary for their scientific aim out from a broad collection of basic and optional sensors available at DLR or they will be invited to bring their own instruments on board. A facilitator of the LSF will guide the STAAARTE user throughout the whole campaign. The trainees will be instructed in all terms that are related to an aircraft campaign such as: how to get a certification for instruments which has never flown on board before; how to prepare flight patterns according to sientific constraints, area restrictions and air traffic management restrictions; how to design air inlet/outlet systems for various purposes;. how to sample and store data via an own or DLR data aquisition tool. How to organize and prepare individual on board data quicklooks. Trainees will be introduced in the special features and limitations of instrument use and data processing of airborne research. The will get a deep insight in the flight facility operating the aircraft as well as in the institutes operating the optional sensors. They can knit interrelationship to scientific groups of DLR operating sensors of common interest. After that training the new users should be able to act as future principle investigator in international aircraft campaigns.

AIRBORNE MICROWAVE RADIOMETER MEASUREMENTS ON AN AGRICULTURAL SITE : THE IROE-STAAARTE MISSION.

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This paper presents an overview of the results obtained during the IROE-STAARTE mission on May 1997on the agricultural site of "Les Alpilles " (South of France), which is a test-site for the EC ReSeDA project. The main objective of this project is the monitoring of soil and vegetation processes using multisensor and multitemporal observation. The role of IROE (co-investigator in this project) was to evaluate the biophysical characteristics of different agricultural crops (i.e. moisture, biomass) by using microwave radiometer, and the synergy between these sensors and SAR or infrared radiometer. The measurements were made by the French airplane ARAT (STAAARTE program) equipped with IROE (Instrument for Radio Observation of the Earth) microwave radiometer (horizontal and vertical polarization) at 6.8 and 10 GHz of central frequencies and two infrared radiometers. Two different flights, at two different incidence angle 20 and 40 degs, were carried out on May 1st and 20 to observe the development of agricultural crops on several test fields. To control the crop and soil properties an intensive ground measurement campaign was carried out during the plant growth cycle. The results confirm a great sensitivity of microwave emission to different crop type and biophysical characteristics. In particular the capability to classify the different crop type and the sensitivity to soil moisture was investigated.

DEVELOPMENT OF THE PLANETARY BOUNDARY LAYER/FREE TROPOSPHERE HEIGHT OVER A HIGH-ALPINE MOUNTAIN STATION: TIME-SERIES STUDY OF AIRBORNE LIDAR TRANSECTS

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Under the recent STAAARTE programme, airborne measurements of climatically important aerosol parameters were measured up to 12 km altitude above the Jungfraujoch (JFJ) high-alpine research station (3454 m) in Switzerland. Simultaneous in situ measurements at the station were conducted to investigate the extent of the planetary boundary layer (PBL) and to assess how representative the site is of the free troposphere (FT). Multiple passes within a 43 km x 37 km grid allowed the development of the PBL over terrain, ranging from 600 - 4270 m, to be monitored using the DLR ALEX Lidar system. A time series of 6 transects over the JFJ station showed that the PBL/FT boundary was surprisingly uniform in height and spatial extent either side of the alpine watershed. The PBL/FT boundary rose from about 2500 m at 0800 hrs (LST = UTC + 1) to about 4000 m at 1300 hrs and remained there till the last transect at 1630 hrs. These are the first comprehensive spatial results rather than in situ measurements to confirm that the diurnal variation in aerosol concentration, observed at most mountain stations, needs to be considered in terms of convective transport and not just photochemical production.

TRANSBOUNDARY FLUX MEASUREMENTS FOR PHOTOCHEMICAL MODEL VALIDATION IN FLANDERS

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One of the most actual topics in environmental policy in Flanders, Belgium deals with photochemical smog episodes during summertime. During the summer of 1995, 32 days were reported with hourly concentrations exceeding 180 µg/m³. In order to provide support for environmental policy decisions, regional scale photochemical transport models as well as statistical prediction models have been implemented. The photochemical transport models have not been validated specifically for photochemical smog episodes in Flanders so far.

The STAAARTE project "Transboundary Flux Measurements for Photochemical Model Validation in Flanders (TFLUX)" will be carried out within the period early July – early September 1998 and will focus on the validation of computer models that are able to simulate photochemical smog episodes. The objectives are: 1) Measurements and calculation of trans-boundary mass fluxes of ozone, NOx and NMHC, 2) Provide a three-dimensional picture of the photochemical smog distribution in Flanders, and 3) Validation of photochemical transport models, focussing on the individual contributions of horizontal advection, vertical advection and photochemical production, which is crucial to any understanding of smog formation.

The presentation gives a brief overview of the objectives of the experiment, the key chemical components and meteorological parameters to be measured and the flight pattern which will be flown (sortie brief).

AIRBORNE OZONE DIAL MEASUREMENTS OVER GREECE ON BOARD THE FRENCH ARAT AIRPLANE DURING THE STAAARTE '96 CAMPAIGN

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Airborne DIAL measurements of the vertical profile of ozone in the lower troposphere were performed over Greece in September 1996 using the ARAT aircraft equiped with the ALTO Ozone DIAL system, convetional gas analysers, radiation and meteorological instruments. Flights along the urban plumes of Athens and Thessaloniki have been carried out, as well as flights over two thermoelectric power plants. The flight level was around 3-4 km heignt with a time resolution of 1-2 min. The distribution of ozone along the flight paths is discussed and related to the emissions of the anthropogenic activities below the measuring points. The obtained data set is compared with measurements over the Agean Sea which corresond to background conditions for the area and show enhanced background values of ozone in the lower troposphere.

MAPPING SURFACE AND ATMOSPHERIC CONDITIONS FOR ENERGY BALANCE STUDIES IN ARID VEGETATED AREAS, BY USING A COMBINATION OF SENSORS ON BOARD THE DLR-FALCON 20E5 D-CMET AIRCRAFT

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In July 1997 two successful flights were carried out in areas of Spain and Portugal under the framework of the STAAARTE (Scientific Training and Access to Aircraft for Atmospheric Research Throughout Europe) Programme. A 80 km line is Castilla-La Mancha, Spain, and another 50 km line is Evora, Portugal, were covered at three altitude levels to allow multiscale studies with the derived multi-resolution remote sensing data. Apart from atmospheric basic sensors, radiation and turbulence sensors, on board the aircraft were a 12-channels Daedalus scanner, a color infrared metric camera, an integrating nephelometer and a LAS-X to measure aerosol particle size distribution. The 400 km line joining both study areas was also covered with some of the sensors to allow studies of low frequency, large coverage, spatial variability, especially for atmospheric parameters.
Two were mainly the scientific objectives of this STAAARTE flights: a) Combined analysis of spatial variability in surface and atmospheric parameters, including multi-resolution information. Unfortunately, in previous field campaigns, atmospheric data and surface data (remotely sensed) were not simultaneously available. Then, the analysis became limited due to the quick temporal changes, especially in atmospheric parameters (including radiation terms). The capability of having strictly simultaneous data will allow strict tests of spatial variability by means of advanced statistical techniques. Multiresolution remote sensing data (as derived from three flight altitudes) provide surface parameters, and atmospheric parameters were continuously acquired in the three flight levels, so that vertical variability plus horizontal variability can be also studied for atmospheric parameters. b) Obtain surface/atmosphere parameters from absolutely calibrated remote sensing data by using theoretical model inversion techniques applied to atmospherically corrected data. The lack of absolutely well calibrated remote sensing data has been a major problem in the past to apply advanced algorithms to actual data. Once absolutely calibrated data are available, one can apply sophisticate techniques for surface information retrieval. Although several techniques have been developed in previous experiments, application of these techniques have been limited to AVIRIS and few other data, due to the difficulties imposed by deficient calibrations. STAAARTE data will be then an opportunity to test and improve the existing methodology.
Although the initial goal of STAAARTE activities were mainly focused in training activities, significant amount of scientific results are expected from the analysis of such large amount of data, and the resulting database will represent a source for research and training activities in the field for the next coming years.

STAAARTE Airborne Measurements - Results from southern WINTEX region

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During the third intensive observation period of NOPEX (A Northern Hemisphere Land Surface Climate Processes EXperiment), the WINTEX, aircraft based measurements of atmospheric quantities and remotely sensed land surface conditions were performed. The WINTEX took place throughout March 1997 and measurement flights were performed during a total of four days at the two NOPEX regions, the southern region at Uppsala in central Sweden and the northern at Sodankyla in northern Finland. The instrument platform utilised is a Lockheed C-130 aircraft operated by the Meteorological Research Flight (MRF) at Farnborough, UK. The aircraft is fitted with instruments measuring basic atmospheric variables, atmospheric radiation, cloud physics, aerosols and atmospheric chemistry. The flights are recorded with forward and downward looking video cameras as well as with hand-held equipment. Results from the flights in the southern NOPEX region around Uppsala during the 14th and 18th of March will be presented. The aircraft measurements were performed in a triangular pattern at several heights over the region and level runs and profile descends and ascends were performed at two sites with intensive ground and tower measurements. Preliminary results from the flights around the Marsta Meteorological Observatory (MMO) agricultural site and the Norunda Central Tower (CTS) forest site will be presented. The results from aircraft measurements over the MMO and CTS sites has been compared and differences between the agricultural and forest sites will be discussed.

EVALUATION OF MIXING HEIGHTS AND OZONE PROFILES DEDUCED FROM GROUND-BASED MEASUREMENTS AND REMOTE SENSING BY AIRCRAFT

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The Austrian Research Fund approved and funded a research project „Dispersion of atmospheric trace elements in an urban area - taking the City of Graz as an example" consisting of numerical simulations with the Graz Mesoscale Model GRAMM to investigate the dispersion and conversion of air pollutants in a generally poor-ventilated urban area under predominantly anticyclonic summer and winter conditions. ZAMG will provide the necessary meteorological vertical soundings by Sodars and tethersondes and turbulence measurements by an ultrasonic anemometer. Boundary layer parameters, the mixing height and the vertical distribution of ozone will be obtained up to a height of approx. 1000 m. The airborne LIDAR observations as well as ozone profiles from the UV absorption ozone photometer provided by the Falcon 20-ES of DLR during STAAARTE will extend these measurements throughout the mixed layer. The flight measurements will be performed in the summer of 1998 in the course of an ozone episode, especially during noon and in the evening transition period. A comparison and a meteorological evaluation between airborne and ground-based mixing height estimates and ozone profile measurements will be carried out.

The STAAARTE – Project
(Scientific Training and Access to Aircraft for Atmospheric Research Throughout Europe)

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Under the Human Capital and Mobility (HCM) Programme, the European Community's Access to Large-Scale Facilies (LSF) Activity was developed on the basis that sharing Europe's resources in terms of large-scale facilities makes sense not only economically but also scientifically. By providing researchers with access to facilities outside their own countries, it promotes the mobility of researchers and encourages the creation of a Europe-wide research community.
There is a wide variety of research objectives, in fields such as atmospheric and environmental sciences, which increasingly depend on the availability of high-capability research aircraft (large-scale facilities). Within the EU-project: 'STAAARTE' 3 unique, extensively modified and instrumented research aircraft including all linked services of the flight facilities are made available to researchers in all EU countries: the Hercules aircraft C-130 of the UK Meteorological Research Flight (MRF), the ARAT aircraft F-27 of the Institut National des Sciences de l'Univers/CNRS (INSU) and the Falcon 20 of the German Aerospace Center (DLR). The STAAARTE project covers all costs for the usage of the aircraft, the operation of the instrumentation, travel and subsistence. Per aircraft about 10 STAAARTE-trainees will have access to about 8-9 flight measuring flight hours.The current STAAARTE contract ends in 1998. An extension of the STAAARTE project until 2000 is presently negotiated with the EC.

REMOTE SENSING STUDIES OVER THE SOUTHERN NOPEX REGION - UPPSALA SITE (EC funded STAAARTE project)

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ABSTRACT
Multi-frequency passive microwave measurements were obtained by the airborne multi-frequency radiometers Deimos (24 and 50 GHz) and MARSS (89 and 157 GHz) over the southern NOPEX test site near Uppsala, Sweden in March 1997. These measurements were performed in order to determine the emissivities of the boreal forest and the adjacent open areas. On March 14 and March 18, the C-130 of the UK Meteorological Office was flown in a triangular pattern at different altitudes above ground level. During the first flight the aircraft flew legs at 500ft, 1000ft (twice), and 3000ft, while on the second flight the same legs were flown at 500ft, 1000ft, and 2500ft. In addition to the passive microwave measurements, the airborne filter radiometer SAFIRE made measurements using the 0.615μm, 0.87μm , 10.9μm , and 12μm filters. Some results from the above flights will be presented. These results will help us obtain a better insight into the behaviour of high frequency signatures from vegetation.

NATURAL HAZARDS (NH)

NH1 Extreme events in the sea and near shore and coastal hazards

01 Sea surges and storms (co-sponsored by NP)

Convener: Osborne, A.R.
Co-Convener: Tinti, S.

CHAOTIC DYNAMICS FOR SYMMETRY-BREAKING PERTURBATIONS OF INTEGRABLE EQUATIONS

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It is well known that for certain parameter regimes the periodic focusing Non-Linear Schrödinger equation (NLS) exhibits a chaotic response when the system is perturbed. When even symmetry is imposed, the dynamics is characterized by irregular center-wing flipping of the wave form and one can prove persistence of transversal intersections of the invariant manifolds as the main source of homoclinic chaos. In this paper we examine evenness breaking perturbations of the NLS. Novel types of chaotic behavior are observed for the non-even case, including solutions which exhibit random flipping between a left and right modulated traveling wave. This behavior is related to an extra circle symmetry in the problem and to random variations of the sign of the linear momentum. A Mel'nikov analysis interpretation of this new phenomena is provided.

CRITICAL CONSIDERATIONS ON WIND CLIMATOLOGY FROM DIFFERENT DATA SOURCES

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The wind climatology in an enclosed basin from three different data sources is analysed. The different considered sources are: the traditional ship reports, an operational meteorological model and a simplified wind model. Evaluation of different statistical parameters such as yearly and seasonal average wind in the whole basin as well as in the three geographical regions: north, centre and south are presented. The differences between the three resulting statistics are analysed and disscussed, leading to conclusions on the reliability and limitations of the different sources.

GENERAL ASPECTS OF MODELLING, FORCASTING AND ANALYZING WIND-WAVE FIELDS AND SEA LEVEL RISING

L. Cavaleri and L. Bertotti (Istituto Studio Dinamica Grandi Masse, San Paolo 1364, 30125 Venice, Italy).

An overview is presented of the present accuracy in evaluating a wave field in different weather conditions. In the case of extreme events, as for example high waves related to storm surge, a good modelling of both wave fields and sea elevation is essential. In the different regions, a specific knowledge of the geographical characteristics of a particular location is needed for a better and comprehensive forecast of the sea elevation in stormy weather. After describing the present results and achieved accuracy, some detailed applications in specific regions will be presented.

STUDY OF A STORM SURGE EVENT IN RIA DE AVEIRO, PORTUGAL

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Until some years ago it was generally considered that storm surge in Portugal was very small and was not a true problem for the portuguese coastal zone. Recent systematic studies from several authors show that the maximum level of storm surge can reach more than 1 m at Aveiro tide-gauge station in extreme conditions.
Ria de Aveiro is a shallow lagoon in the Northwest of Portugal, with a very irregular and complex geometry characterised by narrow channels, connected with the Atlantic through an artificial channel and supplied with fresh water by two major rivers, Vouga and Antuã. This lagoon is a centre of population, commerce, industry and recreation, and consequently is a site for disposal of industrial, agricultural and municipal wastes.
In this work is presented a numerical study of a highly significant storm surge event that occurred on 14-16 of October 1987, with a maximum level of storm surge of about 80 cm. A two-dimensional depth integrated finite difference numerical hydrodynamic model was used in order to predict the water level inside the lagoon. The storm surge maximum was attained during the low neap tide, when the predicted tide-level was very low. If this storm surge episode had occurred during a high spring tide period, the rise in the sea level at the mouth would have reached a very high value, and consequently also the water level inside the lagoon would have been very high, what would induce severe damages along the channels boundaries.

PREDICTION OF COASTAL EROSION AND SHORELINE RETREAT ASSOCIATED TO "MEAN" AND "CENTENARY" STORMS AT THE PORTUGUESE COAST

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Storm action and the lack on sediment supply are the two main causes responsible for coastal erosion and shoreline retreat at the Portuguese coast. In the last few years a strong effort has been done in order to apply and validate simple models for determination of coastal retreat and dune erosion due to storms. One of the models that gave better results when compared with field observations was the convolution method, developed by Kriebel and Dean (1993). In this work, the model was applied to determine the consequences of two hypotetic storms named "mean storm" (mean annual conditions) and "centenary storm" (100 years return period conditions) over the coast between Aveiro and Cape Mondego (Northwest Portugal). The considered "mean storm" presented a significant wave height of 6.2m, acting during 36h over a maximum water level (tide + storm surge) of 1.71m above Mean Sea Level. The applied "centenary storm" (100 years return period) had 13.9m of significant wave height with a total duration of 14 days (336h) over a maximum water elevation of 2.2m above MSL. The model predicted beach erosion volumes between 70 and 110 m3/m for the "mean storm", according to different beach profiles, without prediction of dune retreat. The "centenary storm" would cause erosion volumes between 390 and 680 m3/m with a mean computed dune retreat of about 26 m. The predicted erosion volumes and dune retreat for this storm are able to completely destroy the dune ridge at the most of the tested beaches, inducing severe overwashes and damages.

EXTREME WAVE EVENTS PRODUCING SHIPWRECKS IN THE COAST OF GALICIA (SPAIN)

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Galicia is the Spanish region placed in the Northwest of the Iberian Peninsula. Its coasts suffer very frequently from storms which result in extreme wave events that produce many shipwrecks every year. In this study we analyze those shipwreck events in which people died. We study the meteorological patterns that produce the events by means of different surface and upper levels meteorological charts and we analyze statistical risks of these events.

NONLINEAR QUENCHING OF CURRENT FLUCTUATIONS IN A SELF-EXCITING HOMOPOLAR DYNAMO

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In the interpretation of geomagnetic polarity reversals with their highly variable frequency over geological time it is necessary, as with other irregularly-fluctuating geophysical phenomena, to consider the relative importance of *forced* contributions associated with *changing* boundary conditions and of *free* contributions characteristic of the behaviour of nonlinear systems operating under *fixed* boundary conditions. New evidence –albeit indirect– in favour of the likely predominance of forced contributions is provided by the discovery reported here of the possibility of quenching of current fluctuations in a self-exciting homopolar dynamo driven by a steady couple applied to its Faraday disk. The armature of an electric motor connected in series with the coil of the dynamo is driven into motion by a torque T due to Lorentz forces associated with the electric current I in the system, just as the Earth's solid inner core and certain eddies in the fluid outer core are driven into relative motion by Lorentz forces associated with currents generated by the self-exciting magnetohydrodynamic geodynamo. Supposing that T is proportional to $(1-e)I + eSI^2$ where S A^{-1} is a constant and $0 \leq e \leq 1$, the analysis of the governing set of nonlinear ordinary differential equations shows that the extensive regime of fluctuating (including chaotic) dynamo action found when $e = 0$ is replaced by a completely steady regime of dynamo action in the geophysically more relevant case when $e = 1$, with partial quenching occurring in the intermediate cases when $0 < e < 1$.

MODELLING OF TWO-DIMENSIONAL SEA SURGES OVER THE SHALLOW GENTLY SLOPING BOTTOM

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Dynamics of the essentially two-dimensional moderately long nonlinear water waves is studied. It is assumed that stationary component of flow is absent, the arising boundary layer remains thin, i.e. the time required for the boundary layer to develop over the entire thickness of the liquid is proposed to be much greater than the characteristic time of the wave process. Hence everywhere except the near-bottom region the resulting flow is potential. For weakly nonlinear perturbations propagated mainly in one direction (linear waves may travel simultaneously in any directions) the initial hydrodynamic equations were reduced to the following evolution equation for the water level:

$$\frac{\partial^2\eta}{\partial t^2}-gh\nabla^2\eta-g(\nabla\eta\cdot\nabla h)-\frac{3}{2}g\nabla^2\eta^2-\frac{h^2}{3}\nabla^2\frac{\partial^2\eta}{\partial t^2}+\delta\int_0^t\frac{\nabla^2\eta\,dt_i}{\sqrt{t-t_i}}+\delta_0\frac{1}{\sqrt{t}}\frac{\partial\eta_0}{\partial t}=0.$$

Here t is the time, g is the acceleration of free fall, h is the equilibrium liquid depth; the operator ∇ is defined in a horizontal plane; the coefficients δ and δ_0 depend only on the physical parameters of the system; η_0 is the initial perturbation. Some solutions of the model equation were found numerically.

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SEARCH FOR HIGHER ORDER NON LINEAR EFFECTS IN SHALLOW WATER IN A WAVE TANK FACILITY

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Experimental measurements have been recorded in the wave tank facility (50 meters long and one meter wide) of the University of Florence at various distances from the wave generator. We investigate the case of propagation of waves on a variable depth of slope 1:100. In this condition the motion can be considered almost adiabatic (non linearities increase very slowly with decreasing depth). Sinusoidal wave profiles with different amplitudes and periods are generated at the wave maker and their evolution is followed along all the flume. We show that in many cases the Korteweg-de Vries equation represents a good model of wave propagation (the period matrix in the theta function representation of the periodic solution of the KdV equation is constant). However there are situations in which the non linearity is too strong and a higher order equation is needed to describe the evolution of the waves. In these cases the nonlinear spectral analysis is not so straightforward, since the higher order equation is not integrable. If a transformation on the data is performed, we show that the non linearity is reduced and the data can still be analysed by the inverse scattering method.

INVERSE SCATTERING TRANSFORM I: NONLINEAR FOURIER ANALYSIS WITH CNOIDAL WAVE BASIS FUNCTIONS

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The inverse scattering transform (IST) solves certain nonlinear partial differential equations such as the Korteweg-deVries (KdV) and Kadomtsev-Petvishvilli (KP) equations. KdV describes the nonlinear evolution of wave fields in shallow water in 1+1 dimensions, while KP describes shallow-water wave evolution in 2+1 dimensions. Of particular interest are the solutions to KdV and KP in the θ–function representation: I show that all such solutions for periodic boundary conditions may be written in terms of a linear superposition of cnoidal waves plus pair-wise, nonlinear interactions terms. Using this approach I give specific, concrete numerical examples of solutions to KdV and KP and describe their requisite nonlinear wave physics. Of particular interest is the fact that the cnoidal waves of the KP equation undergo both 'weak' and 'strong' interactions which are explicitly accounted for in the θ–function formulation.

INVERSE SCATTERING TRANSFORM II: NONLINEAR FOURIER ANALYSIS OF ADRIATIC SEA SURFACE WAVE DATA

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The inverse scattering transform (IST) is used to analyze Adriatic Sea surface wave data. In effect we project the data onto cnoidal wave basis functions and study the requisite nonlinear interactions among the cnoidal waves. In effect we invoke a simple theorem for solutions of the KdV equation: All solutions may be written in terms of a linear superposition of cnoidal waves plus nonlinear interactions. We are able to isolate 12 cnoidal waves (degrees of freedom) which dominate the nonlinear dynamics near the peak of the spectrum. We study in particular these waves and their nonlinear interaction components. Of particular importance is the fact that one is able to identify the specific physical influence that the interactions have on the Adriatic Sea wave trains. One finds that the superposed cnoidal waves are modified substantially by the interaction contribution. It is easily seen that the interaction wave train is approximately 180o out of phase with the summed cnoidal waves. This surprising result is interpreted as complex spectral representation of the well known phase shifting phenomenon which occurs, for example, in the collision of two solitons of the KdV equation. We discuss some of the implications of our study on the physics of wind-driven surface waves and their nonlinear dynamics.

LONG-TERM METEOROLOGICAL PRECONDITIONS FOR THE FLOODING OF THE NORTH ADRIATIC COAST

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Events of flooding (*acqua alta*) of the North Adriatic coast are examined through 13-year series of hourly sea-level data, recorded at Bakar. The threshold-exceeding sea levels are studied in respect to three major contributions: (*i*) tides, (*ii*) elevations generated by synoptic and smaller-scale meteorological disturbances (storm surges and seiches of the Adriatic), and (*iii*) low-frequency oscillations ($0.1 < f < 0.01$ cpd) predominantly induced by planetary atmospheric waves, seasonal processes rendering only a minor contribution to the total sea-level maxima. Effects of meteorological forcing associated with the travelling cyclones, being the major contribution to the peak events, have amply been studied, and relative phases of the storm surge, the pre-existing fundamental Adriatic seiche and the astronomical tide have been recognized as the decisive factor for the flooding. However, the lower-frequency, planetary atmospheric waves can give rise to sea-level changes in the range of 70 cm, thus posing strong, days lasting preconditions for the flooding events. It is shown that in the absence of these long-period sea-level variations, the total number of sea-level events exceeding the 99.5% threshold value is reduced more than ten times. Consideration of the forecast of planetary-wave lows, which are best visible at the 500 mbar surface, may significantly improve the prediction of severe flooding events.

CROSS-SHORE DYNAMICS OF SURF ZONE AFFECTED BY STORMS

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The long-term cross-shore dynamics of the surf zone affected by storms is investigated. The validity of the hypothesis of equilibrium bottom profiles in the coastal zone is examined using bathymetric measurements of some coastal regions in Israel for the period 1968-1995. It is shown that the power law of depth variation as a function of offshore coordinate (Dean's profile) is satisfied on the average for non-barred profiles. A mathematical model for description of time- dependent sea bottom deformation under the action of wind waves in the surf zone is developed. It is found that, besides the known static solutions of the balance equation for sediment transport which correspond to the equilibrium bottom profile with zero net sediment transport, there exists a solution corresponding to the profiles of dynamic equilibrium when the surf zone is a "carrier" of sediment transport from the coast to the sea or in the opposite direction. Both equilibrium bottom profiles satisfy the power asymptotic law near shore. A class of steady-state solutions of the sediment balance equation which correspond to the "traveling" bottom profiles is studied also. Data available on the deviation of bottom profiles from equilibrium are used to estimate an anticipated speed of the long-term beach deformation.

WAVE HAZARD MAPPING

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Civil protection contingency plans for wave action on shore require hazard contingency maps that have to be produced and frequently updated. This requires, on the one hand the availability of efficient methods for run-up calculations and on the other hand the setting up of fast procedures for the automatic redaction of computer maps. The paper presents the work which is being carried out within the research activities of the Italian Government Civil Protection Department and the development of the Contingency Plan for the Salerno Province. After an extreme events analysis of sea climate is carried out for deep off shore water; a linear transformation model is employed to estimate the transition from deep into shallow depth water, then a Boussinesq 1d model is used for the region where both amplitude and frequency dispersion take place. Finally then a model of the non linear shallow water equations is employed to calculate the run-up of extreme events on beaches along a number of cross sections. Flooded areas are then defined by making use of the run-up lengths through a CAD implemented interpolation procedure.

INTERNAL WAVES OF EXTREME AMPLITUDES IN THE OCEAN

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Internal waves are a widespread phenomenon in the ocean, which play an important role in its dymamics. Internal waves can produce essential vertical displacements of internal oceanic layers (up to100 m, accompanied by orbital velocities up to 2.0 m/s). Along with the useful function of oceanic ventilation, internal waves can lead also to some undesirable consequences (dangers for underwater navigation, problems in caring out drilling and others). The main purpose of our paper is to review the literature of all known observations of large internal waves, and on this basis to reveal incidences of the largest waves, as well as oceanic regions where these extreme amplitude internal waves occur. Parameters of the biggest internal waves from different regions of the ocean are compared, tabulated and generalized. Typical conditions and causes leading to the generation of large internal waves, and typical observed features are summarized. Some records of huge internal waves are presented. An example of an attack of such an internal wave on a drifting ship is shown.

THE DECEMBER 1939 ANATOLIAN EARTHQUAKE, TSUNAMI CREATED AND THE WEATHER CHANGES

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The well known large and destructive earthquake in Eastern Anatolia on 26 December 1939, seems to be one of the greatest human tragedy during XX century. The reported deaths by the newspapers during this time overgo several tens to hundred thousands. It is well known also that the epicenter of this quake is located far from the Black sea coast but also created the largest tsunami reported during this century and registered at several mareograph stations on the Russian coast. But it is almost unknown that before and immediately after the quake, the extreme and unusual weather changes appear, providing heavy snowfalls, rains and floods propagating from the epicentral area to the south and thus creating very large difficulties to the safety works after the quake as well adding big troubles to the homeless people. The paper suggests the idea supporting by large amount of data, that this weather changes have been created or supported by the quake and tsunami influence to the unstable weather conditions.

TYPHOONS IN CARIBBEAN REGION REGISTERED ON SATELLITES IN VLF BAND

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Analog VLF wide band registrations (0.07-20.0 kHz) from Cosmos 1809 and Intercosmos 24 satellites were made at June-July 1992 on Cuba-station (Havana, Institute of Geophysics and Astronomy). Orbits of this satellites (Cosmos 1809 - circular with h = 950 km, inclination 82.5°; Intercosmos 24 - perigee 500 km, apogee 2500 km, inclination 83°) give us possibility to register VLF information in latitude region from 0 to 50°N, and longitude region from 64°E to 100°W. From different signals, received on satellites (fractionally hop, usual and LHR-whistlers) we choice signals, which are excited by lightning and propagated from earth through the ionosphere to satellites. There signals are related with typhoons in Caribbean region, which accompanied unusual strong lightning activity. Registrations VLF signals were made at night and day times. By day number of signals from lightning were essentially less. It was related with strong attenuation these signals in D-layer of the ionosphere. Many signals have in spectra frequencies 100 Hz with large amplitudes. We suppose that these signals were caused by cloud to-ground lightning discharges. On both satellites a number of signals was increased from latitude 10°N and diminished after 40°N.

NH1 Extreme events in the sea and near shore and coastal hazards

02 Submarine landsliding

Convener: Heinrich, P.
Co-Convener: Eva, C.

NUMERICAL MODELLING OF A SUBMARINE AVALANCHE : THE 1979 NICE EVENT (FRENCH RIVIERA).

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On 16 October 1979, a part of the Nice international airport (French Riviera) slumped into the Mediterrenean Sea during landfilling operations. This submarine landslide, with an estimated initial volume of 10 M of m³, quickly transformed into a debris-flow and then in a turbidity current, that broke two submarine cables across the lower Var fan valley, and generated a small tsunami. Over the last years, several acoustic and submersible surveys were conducted by IFREMER, in order to identify and study the travel path of the avalanche.
2D and 3D fluid mechanics mixture models, developped by the LDG of CEA, have been recently used to better understand this event. A gravitational mass movement is classically divided into a dense flow close to the seabed and a less dense plume above. Within the model, the dense part is considered as a viscoplastic fluid, whereas the dispersed part is modelled by an ideal fluid with a low density. The rheological parameters of the model comprise a diffusion coefficient, a Bingham yield stress, a viscosity coefficient and friction on the slope.
The submarine avalanche has been first simulated by using the 2D model along the travel path. Finally, taking into account a very accurate multibeam bathymetric map, the 1979 event has been modelled by using the 3D version of the model. For each case, the computed density maps are presented at different times, showing the different phases of the gravity flow.

THE LANDSLIDE TSUNAMI OF OCTOBER 16, 1979, NICE, FRANCE

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A submarine slope failure occurred on Oct. 16th 1979 during the construction of the Nice new harbour. This gravitational submarine sliding generated a small tsunami observed by several witnesses in the Baie des Anges. Except one person in Antibes, the victims are working men on the building site. The maximum hydraulic effects were observed 10 km from Nice near Antibes. Photographs of the inundation show water heights of about 1 metre. At La Salis (close to Antibes), witnesses reported a first positive wave of about 50 cm, five minutes after the landslide. This wave was followed by 3 waves of 3 metres high with a period of about 8 minutes. The sliding of this mass and the generated water surface have been simulated numerically, assuming that the landslide behaves like a viscous fluid flowing into the sea. The numerical model solves the 3D Navier-Stokes equations for a mixture composed of sediments and water. The propagation of generated water waves is studied in the Baie des Anges by means of shallow water models.

SIMPLIFIED THEORY OF THE SURFACE AND INTERNAL WAVE GENERATION BY THE SUBMARINE LANDSLIDE

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A problem of the water wave generation by submarine landslides is discussed. At first, this problem is considered in the frame of linear theory when the landslide body motion is approximated by introducing of the mass sources. For small and large values of the Froude number the expression for vertical displacements of the sea surface and pycnocline is obtained in the explicit form. Internal wave field generated by the moving landslide is calculated for different stratifications of water density. Then the problem of the submarine landslide motion taking into account the wave resistance is discussed.

NH1 Extreme events in the sea and near shore and coastal hazards

03 Tsunamis

Convener: Piatanesi, A.
Co-Convener: Baptista, M.A.

DEBRIS AVALANCHES IDENTIFIED ON THE FLANKS OF ALL CANARY ISLANDS

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GLORIA side scan sonar and SIMRAD swath bathymetry mapping of the flanks of the Canary Island group, the Selvagen Islands and the seamounts of the area revealed that giant debris avalanches and other features of landsliding (slumps, debris flows, turbidites) have been most dominant processes of mass transfer from the volcanic edifices into the sediment basins during the last million years. This does not only apply to the recently most active West Canaries, but also to the older East Canaries and Gran Canaria. The large-scale mass wasting encountered in the Canary Archipelago indicates that the long-lived history of volcanic activity of these islands is balanced by a correspondingly long history of destruction, implying that the flux of material from the earth mantle through the volcanic edifices into the ocean basins is a function of mantle dynamic parameters, which are recorded in the sedimentary sequence of the adjacent ocean basins.
Our data set, which has completed the existing side scan sonar coverage of the Canary Archipelago, allows - together with high resolution reflection seismic mapping of the area - an estimate of the potential hazard of giant landslides, which are triggered by volcano flank instabilities and have the potential of creating large tsunamis.

SUBMARINE LANDSLIDES ON THE FLANKS OF THE CANARY ISLANDS

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The flanks of the Canarian Islands are characterized by large landslides which indicate the high flux of sedimentary material from the islands into the adjacent oceanic basins. Multichannel reflection seismic investigations, which have been performed in December 1997, reveal layers with various thicknesses of up to 500 meters. They are normally characterized by chaotic reflection patterns, especially in slump areas, but some of them show clearly internal reflections indicating that complete sedimentary blocks moved downslope.
The landslides can be traced beneath the seafloor of the adjacent oceanic basins, which are characterized by a clear series of sequences with parallel to subparallel reflection patterns. They form partly onlap structures covering older landslides indicating that no mass movements occured in recent time in these areas. The transition from deep sea sedimentation patterns to mass flow structures on the flanks at water depths of about 3.500 - 3.600 meters in the Northern and Southern Canarian Basin is generally rather sharp.
A seismic profile from the deep sea area south of Tenerife shows strong reflectors in a depth of about 500 meters below sea floor, which represent obviously the top of large gas containing layers either of volcanic or organic origin. Smaller vulcanic mounds on the crystalline basement are completely covered by deep sea sediments.

NUMERICAL STUDY OF TSUNAMI AMPLIFICATION OVER THE SOUTHERN SHELF OF CRIMEA

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Tsunami propagation over the southern shelf of Crimea has been studied in a frame of one-dimensional non-linear shallow water equations with usual quadratic law for bottom friction. The scales of marginal slope and shelf zone in the Black Sea are essentially differing in comparison with the Pacific Ocean.
The initial free surface elevation was disposed over deep edge of the continental slope. We have used the empirical relations proposed by K. Iida (1963) between parameters of sea initial disturbance and magnitude M of the underwater earthquake. It is found the wave height H over shelf is 2-3 times as much as initial value H_0. Tsunami run-up R on a vertical wall at 10 m depth can be evaluated from equation $\ln_2 R = aM - b$ which is closed to empirical relation proposed by E. Pelinovsky (1982).

RUNUP OF TSUNAMI WAVES ON GENTLE BEACHES IN A BASIN OF A COMPLEX TOPOGRAPHY

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Runup of tsunami waves on beaches is considered usually as the one-dimensional problem within the nonlinear theory of shallow water. This approach is developed for the description of the runup of tsunami waves in channels and bays with the narrow cross-section when integrated on the cross-section equations have the one-dimensional form. It is shown that if a small- amplitude wave is coming from the deepest water (where the wave is linear) and a beach slope in the direction of a wave propagation is constant, the maximum value of the runup height can be obtained within the linear theory correctly, but not a wave form. Simplified method of calculation of both the wave amplitude and wave form is proposed. Some solutions for the oblique long wave runup are discussed.

THE "PILOT" ITALIAN MONITORING AND ALARM SYSTEM FOR THE CALABRIAN-SICILIAN TSUNAMIS: STATE OF THE ART

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An experimental "pilot" Tsunami Warning System (TWS) is in preparation in eastern Sicily, in the area facing the Catania-Siracusa coastal segment, one of the most important tsunamigenic regions in Italy, in the frame of the GITEC-TWO Project (Genesis and Impact of Tsunamis on the European Coasts: Tsunami Warning and Observations). This system, conceived for those coastlines potentially affected by tsunamis generated by local coastal earthquakes, is designed for the simultaneous acquisition of the seismic signal and the sea-surface displacement, in order to define dangerous conditions and to issue an alarm message to local units of the Civil Protection service. After the selection of the most suitable place and the accomplishment of all the bureaucracy, the station, compound by a water-level sensor, a barometric unit and an automatic station to perform standard test and diagnostic and to transmit the data to the TWS "control center", has been installed. In this experimental stage the sea level data and the seismic signal are collected and studied, in order to develop and test the basic software for data acquisition, data processing and transmission and to define the alarm transmission code. At present, the realization of the acquisition system on PC platforms is in progress at the University of Bologna. The system main tasks should be to control instruments, to manage connections with other remote PC units, to acquire and to analyze the data in real time.

NUMERICAL MODELING OF THE 1996 PERUVIAN TSUNAMI

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The February 1996 Peruvian seism generated a larger tsunami than expected from its surface magnitude (Ms=6.6). This discrepancy as well as the long rupture duration (about 100s) indicate that this event is a 'tsunami earthquake'. The associated tsunami was locally strong in Peru with runup heights of 1 to 5 meters along a coastline of 300 km. It is shown that this tsunami can be modeled for a seismic moment of 2. 10^{20} N.m. and using a rigidity of 2.5 10^{10} N/m^2. The water surface initialization has been computed from Okada's formulas, using seismic parameters of Ihmle (1997). The tsunami propagation has been modeled solving shallow water equations by a finite difference method and using a system of multiple grids with different grid sizes. The maximum run-up heights in the region of Chimbote are modeled using a grid increment as small as 10 meters. The propagation of this small tsunami across the Pacific Ocean has been modeled taking into account frequency dispersion. The only notable amplification occurred in Hiva-Oa (Marquesas Islands, French Polynesia) where wave heights of 2 meters were observed and reproduced by the numerical model.

PALEO-TSUNAMIS IN NORTHWESTERN EUROPE

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Tsunamis are able to cause disasterous damage to coasts and coastal habitation. They are generated by coastal and submarine vertical fault movements or huge submarine slides. It is a well known phenomenon in the Pacific region. The Lisbon 1755 event is classic. In recent years we have also started to appriciate their imprints in our paleo-records. Past events are documented in the Mediterranian region. More surprising are the records from NW Europe. First we learned about the tsunami of the 7200 BP Storegga submarine slide outside Norway and its effect along the coasts of Norway and Scotland. The latest news come from Sweden where we have been able to document a major earthquake (generating liquefactoin over 320 km) occurring in the autumn of varve 10,430 BP and a subsequent event occurring in varve 9663 BP (generating seismites over 210 km). Both events generated tsunamis; the first one washed the strait between the Baltic and the North Sea free of ice so that marine water suddenly could invade the Baltic basin. The second event set up a wave recorded in the ice marginal sedimentology and shore morphology. Further documentation is urgently needed for a better understanding and a proper hazard assessment.

Tsunami from Asteroid and Comet Impacts: The Vulnerability of Europe

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Tsunami is probably the most serious damage caused by asteroids with diameters between about 200 meters and 2 km. Smaller, stony asteroids dissipate most of their energy in the atmosphere. Asteroids larger than 200 m hit Earth about every 3000 to 5000 years, so the chance of such an impact occurring in a human lifetime is about 2-3%. An asteroid 200 meters in diameter impacting the mid Atlantic Ocean would produce tsunami 10's of meters high on either side of the ocean basin. Using a tsunami propagation and runup code, we find that an asteroid 5 kilometers in diameter falling in the mid Atlantic Ocean would produce a series of tsunami that inundate the upper two-thirds of the Eastern United States up to the foothills of the Appalachian mountains. In Europe the damage is less dramatic: The most vulnerable area of Europe is the Spain-Portugal peninsula. It is being thrust into the Atlantic with little continental shelf producing idea conditions for tsunami runups. The same impactor that causes runups in the Eastern United States to the Appalachian mountains would cause runups to the mountains of this peninsula. The situation in Northern Europe is more favorable. The gradual continental shelf that the U.K. pops out of reflects much of the tsunami energy back into the Atlantic. The U.K. and parts of the continent facing it are relatively protected from tsunami.

THE TSUNAMI GENERATION AS A PROCESS RUNNING IN THE COMPRESSIBLE FLUID

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The comparative studies of the waves generation by bottom displacements in the compressible and incompressible ideal fluid carried out in the framework of linear potential theory. The analysis of the exact analytical solutions of the problem has showed an essential difference which exists between compressible and incompressible fluid behaviour under ordinary tsunami source conditions. The range of the applicability of the linear theory as well as general non-linear phenomena was estimated. It was also shown that each tsunami source should have its own "voice" which characteristics depend on the bottom topography, sediment features as well as on the time history and spatial distribution of the bottom displacements. This "voice" may serve as an additional important factor for the reason of the tsunami warning.

SEDIMENT SLUMPING IN THE SOUTH AEGEAN SEA AND THE CASE HISTORY OF THE 1956 TSUNAMI

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The most tsunamigenic areas in Europe are the Ionian and Aegean Seas in Greece. The Cretan Trough, in the Aegean, has since antiquity been the site of many tsunamis. The latest example include a 25 m. high tsunami which occurred on July 9, 1956 south of Amorgos Island which was associated with an M_s=7.5 earthquake. In this paper we first examine the possibility that a large sediment slump produced the 1956 tsunami in the Cretan Trough and we investigate historical movement of the slump to determine periodicity. Second, we investigate the cause of the 1956 seismic event. We found that in certain sectors of the Trough (i.e. the Argolikos and Amorgos Basins) the mean periodicity of the occurrence of a large sediment slump is from 50 to 100 years, elsewhere in the region periodicity is over 500 years. The generation of the 1956 Amorgos tsunami is attributed to the combination of the reactivation of a large normal fault to the south of the island and to the generation of a large sediment slump in south Amorgos Basin. The latter was triggered probably by the largest aftershock of M_s=7.2 of the 1956 earthquake which occurred 13 min. after the main shock. The epicenter of this large aftershock was located in the slump source area.

NUMERICAL SIMULATIONS OF THE OCTOBER 4, 1994 SHIKOTAN (KURIL ISLANDS) TSUNAMI

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On October 4, 1994 an earthquake of magnitude M_w=8.2 occurred off Shikotan, one of the Kuril islands. Seismic wave inversions indicate a thrust type mechanism with a large strike-slip components, that does not represent an underthrust event at the subduction interface. The earthquake generated a large tsunami that was recorded at several tide-gauge stations in Japan (Hokkaido and Honshu islands), in Tahiti and in the pacific coast of USA. A post-event field survey showed that in the source area the inundation was remarkable, with a maximum run-up of about 10 meters at Dimitrova Bay, located in the south-eastern part of Shikotan island, just in front of the estimated epicenter. In this work we perform some preliminary numerical simulations of the tsunami generation and propagation, taking into account different seismic sources. The model is based on the shallow water equations, solved numerically by means of a finite-difference method: a mesh refinement around the tide-gauge stations leads us to compute quite reliable marigrams and to compare them with the recorded one.

SURFACE WAVE THEORY APPLIED TO THE PROBLEM OF TSUNAMI EXCITATION AND PROPAGATION

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A new approach was applied to the problem of excitation and propagation of tsunami waves. Tsunami was considered as a surface wave of interferentional type. This approach allowed to estimate the displacements of ocean surface caused by an earthquake with the seismic moment high enough to generate a tsunami. Calculated displacements are in close agreement with the observed ones. It is shown that the rise in the amplitude of a tsunami wave results not only from the depth decrease as previously assumed (Green-Airy formula) but also from the compression of the wave packet caused by a change in the characteristics of dispersion. Influence of the characteristics such as the elastic parameters of the bottom and thickness of the liquid layer on the excitation and propagation of tsunami wave was also investigated.

IDENTIFICATION OF THE SOURCE FAULT OF THE 1908 MESSINA EARTHQUAKE THROUGH TSUNAMI MODELING. IS IT A POSSIBLE TASK?

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The 1908 Messina Straits tsunami is the last catastrophic event that hit the Italian coast. The parent earthquake may be considered one of the strongest shocks reported in Italian seismic catalogues. Several source models have been proposed in the literature that are quite different with regard to almost all the fault parameters. The aim of this work is to evaluate if using tsunami data can contribute to identifying the fault mechanism of this earthquake. To this purpose we considered most of the faults proposed in literature and simulated the consequent tsunami. Two such faults were already examined in a former work by the authors. The results were in a satisfying accordance with observed data for the polarity of the first wave, but not for the run-up data. The present paper represents a continuation of the previous work since other faults are considered and a heterogeneous slip is allowed on the fault to possibly improve the agreement with observations.

MODELLING A POSSIBLE HOLOCENE LANDSLIDE-INDUCED TSUNAMI AT STROMBOLI VOLCANO, ITALY

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Stromboli is a volcanic island in the Aeolian archipelago in the southern Tyrrhenian sea known for a persistent state of activity. Its main morphological feature is a steep depression marking the NW seaward flank called Sciara del Fuoco. It is interpreted as the partially filled scar of a large flank collapse that took place circa 5000 years ago. The large volume of material estimated to be involved in the collapse was very likely responsible for the generation of big ocean waves. Recent history shows that Stromboli has been affected by tsunamis probably generated by small-scale gravitational instability of the Sciara del Fuoco. This paper presents a numerical simulation of the possible holocene event. For the landslide we used a Lagrangian model based on the discretization of the total sliding mass in blocks of constant volume subjected to external and internal forces. The tsunami was simulated using a finite-element model based on the nonlinear hydrodynamic equations. Wave propagation and time histories all around the island have been computed.

NH2 Meteorological and hydrological hazards (joint with HS)

01 Uncertainty assessment in meteo-hydrologic warning

Convener: Todini, E.
Co-Convener: Castelli, F.

A STATISTICAL METHOD FOR DESCRIBING UNCERTAINTY IN FLOOD FORECASTS FROM A HYDROLOGICAL RAINFALL-RUNOFF MODEL BASED ON METEOROLOGICAL FORECASTS

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The uncertainty associated with a flood forecast is important for risk assessment and useful in the decision making process. For example, the probabilities of exceeding certain critical levels may be more informative for a decision maker than the expected flood. Therefore, it is useful to quantify this uncertainty and incorporate it as part of the forecasting routine. For flood forecasts based on a rainfall-runoff model, the calibration error of the rainfall-runoff model and the effect of uncertainty in the meteorological forecasts are taken into account. A statistical model is fitted to two years of simultaneous values of the 1-6 days ahead forecasts of temperature, precipitation and runoff for two catchments in Norway. The calibration error of the rainfall-runoff model is estimated from 10 and 40 years of daily observations from the same two catchments. Our analysis indicates that the forecast errors are approximately proportional to discharge, and have an autocorrelated structure. An autoregressive model was fitted to each catchment, with stratification on temperature, precipitation and snow cover. The resulting model gives prediction confidence intervals given meteorological and hydrological forecasts. We illustrate the use of the model on a verification data set.

COMBINING LIMITED AREA MODELS QUANTITATIVE PRECIPITATION FORECASTS WITH GROUND MEASUREMENTS

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During flood events decision makers must take decisions under the uncertainty of future events. It is therefore necessary to provide not only a forecast, but also an estimate of the probability distribution of forecasted discharges. Given the non-linearity of the rainfall-runoff processes, this is generally done by generating future realisations with stochastic models of precipitation and by transforming these precipitation traces into runoff with the appropriate hydrological models.
In general the stochastic generation of future rainfall tends to depict a very uncertain future with a standard deviation of the distribution which rapidly increases with the lead time.
Recently, meteorological Limited Area Models (LAMs) are being extensively used to produce quantitative precipitation forecasts (QPFs). Unfortunately at present, LAMs still provide QPFs with a large degree of uncertainty, although this uncertainty does not depend on the forecasting lead time.
The first step of this work was to assess the quality of the LAMBO (a LAM operationally used in Emilia Romagna):.the forecasts were compared to the values measured using a dense raingauge network on the Reno river and biases as well as error variances were derived.
Successively, after generating a set of future precipitation traces by means of a stochastic nearest neighbour approach, the deterministic LAM forecast was used as a biased and uncertain measure of the future rainfall occurrences, within the frame of a Kalman filter scheme, to correct the a priori generated series.
The results, which show interesting properties in terms of bias reduction as well as in the reduction of the uncertainty, may be operationally used to provide the required discharge forecasts together with an estimate of their distribution.

DOWSCALING OF RAINFALL PREDICTIONS AND UNCERTAINTY IN THE ASSOCIATED FLOOD EFFECTS AT THE GROUND

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One major concern in the operational use of rainfall predictions obtained from numerical meteorological models is that forecasting is provided in terms of integrated quantities over a resolution grid of the order of 100 km in space and 3/6 hours in time. In all cases where the catchment size is smaller than the model resolution in space, and consequently the hydrological response time is shorter than the resolution in time, some downscaling of rainfall predictions is required. This involves introduction of additional uncertainties with respect to those already present in the meteorological prediction chain, due to the structure and parameterization of the mesoscale models used. Following the downscaling exercise, distributed hydrological rainfall-runoff models can be used to determine the expected flood peaks in all catchments that are covered by the predicted rainfall field. Some preliminary results are presented about the downscaling of rainfall predictions obtained by LAM, using a simple algorithm based on the separation of the rainfall fluctuations in space and time. Fluctuation in space are synthetically generated in the form of a Gaussian bi-dimensional field with zero mean, unit variance and specified correlation structure. The correlation in time is derived from that in space in the hypothesis that the coherence of scale in the outcoming rainfall field is preserved. Results of the simulation of the extreme precipitation event observed on September 1992 over western Liguria (Italy) are presented in terms of flood peak estimates.

UNCERTAINTY PROPAGATION IN RAINFALL-RUNOFF MODELS

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A numerical procedure to propagate rainfall and parameter uncertainty through rainfall runoff models is presented. The method takes a numerical sample of the rainfall input PDF and model parameters PDF and governs the downstream uncertainty propagation through a network of model components. Each model component receives multiple input and generates multiple output through a combination of rainfall and parameter alternatives. Hydrograph combination is performed at connecting elements, where the number of alternatives is reduced to a manageable size. Three selective criteria may be applied to prevent the combinatorial explosion as the information flows downstream: synthesis, similarity and relevance. A numerical experiment to test the validity of the proposed model is presented.

A STOCHASTIC APPROACH TO SPACE-TIME RAINFALL FORECASTING

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The MTB stochastic space-time rainfall model has been developed for generating ensemble forecasts conditioned on radar images. The MTB model is continuous over space and time, and reproduces the features of observed rainfall fields at four distinct scales: raincells, cluster potential regions, rainbands and the overall outline of a storm at the synoptic scale. An inversion procedure has been developed for inferring a construction of the MTB model from a given sequence of radar images. This procedure is then used to generate ensembles of future rainfall scenarios for various time origins which are consistent with a currently observed storm. The ensembles are converted into ensembles of flow forecasts for the Brue catchment in South-West England, to demonstrate the feasibility of the approach for real-time flood forecasting.

UNCERTAINTY ASSESSMENT OF EXTREME RAINFALL FORECAST

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Meteorological quantitative precipitation forecast (QPF) models are promising techniques for improving hydrological real time forecast performance. The usual assumptions underlying QPF models do not allow to easily deal with the evaluation of predictive uncertainty. Arbitrary distributional assumptions are often induced in the model in order to achieve this purpose. At the present time, a suitable alternative is offered by hydrological precipitation forecasts obtained by stochastic models based on rain-gauge network records or weather radar image. Bayesian forecasting offers a natural approach to the evaluation of predictive uncertainty. The procedure requires the specification of a likelihood function and a prior distribution for the predictions. The posterior distribution is then evaluated recursively from the data as new observations become available. A measure of uncertainty is generated via the estimation of posterior distributions for predictions. Practical operational hydrologic models usually deal with areal precipitation forecasts obtained from areal or multisite observations. For this purpose the previously mentioned procedure must be associated with a technique for the spatial aggregation. The present work mainly regards the former step. In order to illustrate the procedure, an application to rainfall data recorded in a dense rain-gauge network located in Arno basin is presented. Particular attention will be payed to the analysis of very extreme events (outliers), typical of mediterranean regions.

NH2 Meteorological and hydrological hazards (joint with HS)

02 Prediction of hazardous events of meteorological origin

Convener: Tibaldi, S.
Co-Convener: Alonso, S.

SENSITIVITY EXPERIMENTS ON THE RESPONSE OF LAND SURFACE WITH THE COUPLED MODEL RAMS-LSPM.

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A coupled model of RAMS mesoscale model (version 3b) and a well-developed land surface processes model (LSPM, version 3.0) has been established. The aim of this work was to improve the regional water balance representation, in order to reproduce the regional climate in a more accurate way.
The important elements for regional water balance such as precipitation, evapotranspiration, surface runoff, infiltration and bottom drainage processes have been included in the coupled model. Some sensitivity experiments to soil and vegetation parameters (such as soil type, initial soil moisture content, vegetation coverage, minimum stomotal resistance, leaf area index and canopy resistance) have been done, and the results have been simultaneously compared with the ones of the original RAMS3b surface model. The results show that the coupled model RAMS-LSPM produces more realistic estimates of the apportionment between sensible and latent heat fluxes with respect to the original surface scheme.

NEURAL NETWORKS FOR DATA QUALITY CONTROL

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The understanding of data on atmospheric processes requires ever new handling techniques in order to cope with the large amount of complex information collected by direct and remote sensing measurement systems. The growth of automatic instruments capable of unsupervised operation simplifies the collection of these data and their storage, but the data end up in memory without having undergone checking. The restoration of an incomplete time series of data and the resolution of the outliers present many difficulties and there are just a few methodological proposals on this topic. The present research illustrates the use of a neural network in data quality control and reconstruction. The approach consists of training through a back propagation supervised procedure a neural network of fixed architecture, comparing real to virtual data produced by the network. Neural networks are applied to the problem of interpolating and extrapolating daily maximum temperature as well as to nowcast of tropospheric ozone concentration values. Different network architectures are explored and applied to a number of time series of data measured in different places and/or in different time periods. Observed and predicted data are compared to test the efficacy of neural algorithms in predicting environmental processes. To understand the operation of neural networks it is useful to work with simplified network architectures. As an example, results are reported using networks with only one input neuron, one hidden layer with three neurons, and one output neuron. The results presented show that neural models not only represent an efficient alternative to classical models, but also allow improvements in data quality control and in short term forecast.

SIMULATION OF A SEVERE WEATHER EPISODE IN PIEDMONT (3-5 NOVEMBER 1994) USING THE COUPLED MODEL RAMS-LSPM.

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A coupled model of RAMS mesoscale model (version 3b) and a well-developed land surface processes model (LSPM, version 3.0) has been established. This coupled model has been used to simulate a severe weather process which leads to the disastrous flood in north Italy during 4-7, Nov., 1994, simultaneously compared with the observations and the original version of RAMS3b. The geopotential, the stream lines and temperature and humidity fields are represented almost equally by the new version RAMS3b and by the old one. On the contrary, the differences of the land surface sensible and latent heat fluxes are large, and this fact causes a considerable differences between the the precipitation calculated by the two versions. The main differences exsists in the response of soil to the precipitation. The soil moisture of the old version RAMS3b never saturates under the strong input of precipitation, while in the coupled model the soil has been saturated for one day causing strong surface runoff, which constitutes the flood.

USING PROBABILISTICS DISTRIBUTION IN A REAL TIME FLASH FLOOD FORECASTING SYSTEM

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Efficient flood warning in rural catchments requires lead-times of at least 6 to 12 hours, while nowcasting in mountainous regions cannot provide forecasts beyond 1 or 2 hours ahead. So the flood forecaster should use as input to his hydrological models rainfall scenarios which may be derived by different techniques.
Our first aim was to build a rainfall generator conditioned by the immediate observed past while respecting the climatological structure of storms. Next this paper shows that conditioning by the expected future is fruitful. Here the forecast used is expressed as the conditional distribution of the daily totals expected over a fixed time window. Moving from the current day to the next can be smoothly managed by using progressively a mixture of the forecast for the current day, partially elapsed, and of the forecast available for the next day.
An example is displayed on the upper part of the Ardèche river basin (121 km²). It is shown that using the future for scenarios is more informative that using only the immediate past, in terms of discharge forecasting.

FROM FLOOD FORECASTING TO REGIONAL WARNING.

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The morphology of the Northern Mediterranean coastline is made up by small-medium catchements (10-1000 km^2) historically developed by a number of villages and cities. Final flood plains had been developed in the past centuries by reducing braided riverbeds into narrow channels which design was based on the past centuries hydrological experiences. By this reasons inundation events of historical city centers are very frequent and proper civil protection policies require to issue during the flood season early warning messages to risk exposed population. Space and time scales of the available meteorological deterministic models exceed the size of most catchements. To quantify the uncertainty of the rainfall inputs is quite difficult. Past decade extreme events evidence over the Liguria Region is presented. Events are described by LAM outputs, Meteosat images and ground observations. Coherence between predictions and ground effects of rainfall events is also discussed. Experimental evidence suggests that robust methods are required to estimate in advance risk conditions leading to early warning diffusion. The space scale of Ligurian watersheds and the inherent meteorological inputs uncertainty require to target to ample subregions the early warning. A few examples of true and false alarms are finally discussed.

UNCERTAINTY ASSESSMENT IN THE PREDICTION OF EXTREME RAINFALL EVENTS: AN EXAMPLE FROM THE CENTRAL SPANISH PYRENEES

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Extreme pluviometric events are very unfrequent in time and very erratic in space. In general, they affect few square kilometres in their most active part, as several catastrophic rainfalls have demonstrate (i.e. the flood in Biescas, August, 7, 1997) and their identification in meteorological data.series is very difficult As a consequence, it is almost impossible to make an accurate prediction of extreme events using the traditional statistical procedures. The irregularity is even greater in mountain areas, where a complex topography encourages the generation of isolated rainstorms. In this paper the application of the Gumbel formulae to a dense rain gauge network (in the Central Spanish Pyrenees) confirms the impossibility of predicting the most hazardous areas: In fact, for a given expected precipitation in 24 hours, the predicted return period can oscillate several magnitude orders even in places located less than 20 kilometres apart.

THE USE OF ARTIFICIAL NEURAL NETWORKS OVER THERMODYNAMIC DATA FOR EXTREME RAINFALL EVENTS CLASSIFICATION AND FORECASTING

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The knowledge about the data obtained from the radiosounding ascents are essential for the forecasting, analysis or diagnostics of weather. Particularly the atmosphere's thermodynamic analysis makes it possible to obtain information about the possible existence of instability or about an auspicious environment for convection, the contents of water vapour as well as the possible formation and development of clouds, and the existence of wind's shear and jet streak. The thermodynamic analysis has a highly discriminating feature in those situations in which the synoptic situation does not allow to completely justify either the atmospheric phenomena nor their distribution. On the other hand, artificial neural networks represent an emerging technology rooted in many disciplines. They are endowed with some unique attributes: the universal approximation and the ability to learn from their environment. The objective of this presentation is to show the use of artificial neural networks over thermodynamic data for extreme rainfall events classification and forecasting in Catalonia, Spain, using the radiosounding ascents of Palma de Mallorca since 1975 until 1989. We have tested different inputs (precipitable water mass, equivalent potential temperature, CAPE and so on) and different learning processes. The results obtained have allowed to select the most representative variables and to classify the different rainfall events in relationship with the thermodynamic variables.

USE OF THE REANALYSED DATASET OF THE NECP/NCAR TO IMPROVE DAILY QUANTITATIVE PRECIPITATION FORECAST BY AN ANALOGUE TECHNIQUE

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The NCEP/NCAR reanalysis project has produced a 40-year (1955-1995) record of global analyses of atmospheric fields, through the same model. It offers very interesting perspectives for forecasting methods based on analog techniques, because they are mainly reliant on the length, the homogeneity and the fullness of the historical data file. That's why these re-analysed dataset is being tested in a daily quantitative precipitation forecast method using analog situations sorting out.
The analogy criterion, initially a simple Euclidean distance, has been successfully replaced by the Teweles-Wobus score applied on 700 and 1000 hPa geopotential fields. But these fields, stemming from Electricité de France and Météo-France, are not very homogeneous because they have been modified every time the meteorological model has changed.
So, at first, we will present significant results obtained by changing the analogy criterion into the Teweles-Wobus score. Then, these results will be compared with those obtained with the same geopotential fields (700 and 1000 hPa), but reanalysed by the NCEP/NCAR. And finally, we will also try to enter, in the analogy criterion, new information from the NCEP/NCAR dataset, like humidity at low level, high geopotential fields, potential vorticity, wind ...

SYNOPTIC AND MESOSCALE DIAGNOSIS OF A HAILSTORM SITUATION IN EASTERN SPAIN

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On 4 September 1995, several convective cells developed inland of eastern Spain during the afternoon. As these storms grew and moved toward the Mediterranean Sea, a hail event occurred during the evening in the Valencia region. Hailstones attained diameters of up to 7 cm, and the resulting losses in the grape production of the affected area were very important. The meteorological situation was characterized at upper levels by a deep trough that evolved over the Iberian peninsula. The associated low-pressure centre at low levels absorbed and intensified a preexisting relative low off the eastern coasts of Spain. Synoptic ingredients favourable for deep convection have been identified over the area where convective cells developed. An investigation of the mesoscale features reveals the existence of a low-level convergence line over eastern Spain produced by the aforementioned pressure lows, and a dry cold air tongue introduced into the Mediterranean from the north by a Genoa Gulf low pressure centre. Satellite pictures show the presence of two jets at two different levels of the upper troposphere, which ageostrophic circulations favour the convection development.

NUMERICAL SIMULATIONS OF INTENSE PRECIPITATION EVENTS USING THE ETA MODEL

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During recent years the Alpine region was affected by several intense precipitation events which caused serious damages and loss of human lives. In this respect it is of crucial importance the correct meteorological forecast of the events which can be the cause of potentially dangerous situations. The Alpine region and the Mediterranean area in general present features that can heavily influence the local atmospheric flow and the related phoenomena. The occurrence of heavy rain over small regions should require synoptic scale and mesoscale conditions favourable to the development of persisting upward motions and moisture convergence.
In the framework of the international MAP project (Mesocale Alpine Programme) some events of the kind described above were selected and are currently object of intensive study, also using numerical models, in order to understand in details the features of the related atmospheric flow. Therefore, simulations of some of these episodes using a mesoscale operational model were performed and the results will be shown, with particular attention to the quantitative precipitation prediction. The model used is the Eta model, version 1993, which is operational at NCEP, USA. Comparisons with ECMWF analysis and with observed precipitation data will also be shown.

NUMERICAL SIMULATIONS OF THE VAISON LA ROMAINE FLASH FLOOD

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Numerical simulations with the nonhydrostatic anelastic model Meso-NH are carried out to reproduce the flash flood which occurs in the city of Vaison la Romaine. This flood is the result of several mesoscale convective system which develop ahead of a cold front in the southern part of the Alps. In many aspects, this case appears as a prototype case for the preparation of the MAP (Mesoscale Alpine Program), which will study convection on the Alps as one of its main purpose. Meso-Beta and meso-Gamma scale phenomena will be discussed with the help of nested simulations, using meshes equal to 20 and 2.5 kilometers. Quantitative comparison with rain gauge and radar observations will be used to validate the simulations. Then, the orographic and sub-synoptic influences (cut-off low and streamer) will be analysed for the convection triggering in both simulations in order to understand this complex case.

DEVELOPING VERSUS NON-DEVELOPING CONVECTIVE VORTICES INTO "HURRICANE-LIKE" CYCLONES OVER THE MEDITERRANEAN SEA

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Beyond the more common, baroclinic, orographically induced lee-cyclones, a different category of sub-synoptic scale vortices, dominated by intense convection, has been documented in the Mediterranean in late summer, fall and early winter. Some of these vortices develop a "hurricane-like" structure. Dynamics and classification of these vortices are discussed by O. Reale (OA12 session).
In this presentation, two years of the National Center for Environmental Predictions (NCEP, USA) Medium Range Forecast (MRF) model's output are analyzed: 1996 and 1997, emphasizing the 48 and 72 hour forecast. During this period, 4 sub-synoptic vortices with a hurricane-like structure were detected. They were all correctly predicted, but the model forecasted the insurgence of 5 other events which actually did not develop a hurricane-like structure.
In this study it is shown how some dynamical criteria adopted for the Tropical regions to distinguish between developing and non-developing convective vortices, can be successfully applied in the Mediterranean, thus reducing the over-forecasting error in the NCEP model. Particularly, barotropic instability is an important source of energy, wehereas baroclinic instability acts as an inhibiting mechanism: their evaluation in the model's output represents a good predictor.

STUDY ON THE ROLE PLAYED BY A MINOR MOUNTAIN CHAIN IN TRIGGERING DEEP CONVECTION

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Numerical Weather Prediction models allow the investigation of the interaction of the atmosphere with mountain chains. It is well known that warm and moist overrunings and low-level moisture flux convergence can be strongly amplified by orography, with large increase of precipitation as a consequence. Moreover, vertical motion and convection can be triggered and enhanced by orography. All these events, but particularly the latter, are obviously underestimated by General Circulation Models, which cannot describe the spatial variability shown by precipitation fields over areas in which the orography scale displays a high spatial frequency. Therefore, for regions with a complex and steep orography, like Liguria, the use of very high resolution models is needed.
In order to evaluate the effect of a minor mountain chain (the Apennines, Italy) on the atmospheric mesoscale flow, a simulation of some extreme events, that affected the western Mediterranean producing high precipitation amounts and floods over Liguria (Italy), have been performed with the Limited Area Model (LILAM) operationally used to make weather forecast in our centre. The aim of the present work is to investigate the role played by a minor chain in modifying the small scale atmospheric flow, with emphasis on the role played in triggering deep convection.

HEAVY PRECIPITATION QUANTITATIVE FORECAST: A COMPARISON BETWEEN MEASUREMENTS AND LIMITED AREA MODELS OUTPUTS.

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Heavy precipitations may frequently occur in all mediterranean area, particularly in regions with a steep and complex orography like Liguria. These precipitations caused flash floods with life and property losses. The severity of some of those recent events justifies the research efforts aiming at improving quantitative rain forecasts. The forecast accuracy of heavy precipitation and flood hazards is obviously associated with the skill of rainfall forecast in space and time. It is well known that atmospheric General Circulation Models (GCMs) provide precipitation fields which, at a resolution not suitable for weather and hydrological predictions in areas with steep orography, mostly because of small-scale phenomena caused or triggered by orographic response. Therefore, for regions with a complex and steep orography, like Liguria, the use of a very high resolution model is needed.
Our aim is to compare forecasted and measured rain for a set of events characterized by heavy precipitations in the Ligurian Region, most of them causing floods. To do this we compared distribution patterns of precipitation values forecasted by Limited Area Models operating at different resolutions.

OPERATIONAL USE OF REAL-TIME FLOOD FORECASTING

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Following a brief overview of the state of the art in real-time data acquisition and flood forecasting, this paper aims at presenting a number of real-time flood forecasting and warning systems, operationally installed in Italy as well as in Germany and in China, based upon the European Flood Forecasting Operational Real-Time System (EFFORTS) originally developed at ET&P on behalf of the Commission of the European Communities.
Problems encountered and the use of forecasts in the decision making process aimed at reducing the risk due to flooding, will be discussed. Finally, a recent example of application for the management of lake Como in Italy will be presented. In this application real-time flood forecasting is combined to a real time stochastic optimisation algorithm in order to increase the expected value of benefits deriving from the use of waters (irrigation and hydro-power) while reducing the expected damages due to the flooding of Como main square.

NH2 Meteorological and hydrological hazards (co-sponsored by HS)

03 Flood hazards and flood risk: regional analysis of extremes (co-sponsored by OA)

Convener: Bois, P.
Co-Convener: Oancea, V.

LAST YEAR SUMMER FLOODS IN MORAVIA: WHAT IS THE FUTURE?

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Dramatic floods occurred in Central Europe in summer 1997, Czech Republic being afflicted especially in its eastern part - Moravia. Predictive approach when modeling flood recurrence may be helpful in flood management. Summer floods are typical by saturated catchment due to long-lasting heavy precipitation followed by an extreme rainfall. We analyzed temporal variability of precipitation time-series by fractal analysis, revealing persistent fractional noise with dimensions of 1.3-1.4. Precipitation appears to be a random small amplitude fluctuation superposed on a background controlled by more regular quasi-cycles. While the individual up-down runs last 3-5 years, the persistent trends may take more than 15-30 years. The precipitation character in Moravia, being declining with a rate of 2-5 mm/yr during the past 30-35 years, changed suddenly to the opposite tendency following the dry period of 1992-94. We modelled precipitation fluctuations with the Mandelbrot's fast fractional Gaussian noise tecnique. Simulations were used for stochastic prediction of the precipitation trends causing summer floods. Our results seem to give evidence that higher precipitation in the last years is not a sort of provisional run but belongs to a persistent trend.

FLOOD PREDETERMINATION MODEL BASED ON HOURLY RAINFALLS STOCHASTIC GENERATION

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For the needs of hydrological studies, a hourly rainfall stochastic model has been developed to be coupled with a rainfall runoff conversion model. Thus, many hourly flood scenarios are obtained by simulation on very long periods. The hourly rainfall model has been improved and tested on a large area, 49 raingauges located on the French Mediterranean seaboard. With the rainfall generated, flow time events are simulated with the conceptual spatially-lumped model GR3H. The method has been tested on 17 watersheds on the studied area and gives good results. The advantage of this approach is to obtain rainfall and runoff temporal information. Different realistic flood scenarios, which occurrence is obtained by simulation, are used instead of a unique design flood. Moreover, the large use of rainfall information and the rainfall runoff conversion modelling seems to give a more important stability to this approach rather than the classical statistic methods.

REGIONAL ESTIMATION OF HIGH INTENSITY SHORT DURATION RAINFALL EVENTS

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The procedure for regional estimation of excess probability has been applied to high intensity short duration rainfall events in order to evaluate the flood hazard in Ligurian catchments. TCEV - Two Components Extreme Value - probability distribution has shown excellent descriptive and predictive capabilities, as compared with usual EV probability distributions. The determination of scale parameter has been performed by linking ground observed historical data with remote sensing observation of the typical extreme storm structure over the region. The observed variability of the scale parameter across the region suggests that the maximum annual short duration rainfall depth process has its central measure controlled by a simple physics. Convective processes over Liguria region are mainly driven by orographic uplift: the relative angle between the southern slope of the Ligurian Apennines and the direction of largest S-N fetch seems to control the intensity of deep convection. Experimental evidence is presented

THE FREQUENCY OF LOW MAGNITUDE FLOODS: A STUDY OF THE RELIABILITY OF THE ANNUAL MAXIMUM SERIES METHOD

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The analysis of annual maximum series is a standard procedure used to establish the recurrence of floods of a given magnitude; however, it ignores subordinate peaks of some years which exceed the lowest maxima of the series, and thus underestimates the occurrence of low magnitude floods. To determine the reliability of the AMS method, frequency distributions of low magnitude floods derived either from annual maxima (AMS) or from all peaks exceeding a selected threshold discharge are compared for a set of gauging stations located in the upper Vistula River drainage basin, but on streams with somewhat different flood regime and a range of catchment areas. A considerable variation in the mutual relation of the two series exists among the stations despite their close proximity. The high variation remains even when the recurrence intervals of the AMS are transformed to their equivalents in the partial duration series by means of the Langbein relationship. The divergence between the AMS and PDS increases with growing variability of the annual maximum discharges, and generally, the underestimation of flood discharges of a given recurrence interval by the AMS is high for streams with a flashy regime, but low for streams with more uniform run-off. This study shows that the actual flood magnitudes for a given probability cannot be satisfactorily obtained by means of a simple transformation of the recurrence interval for known AMS discharges. Therefore, despite the long tradition of using the AMS method, it is recommended that the partial duration series method should be employed when evaluating the occurrence of low magnitude floods.

A METHODOLOGY FOR THE ESTIMATION OF THE IMPACTS OF CLIMATE CHANGE UPON FLOOD FREQUENCY (WITH UNCERTAINTY)

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A modelling strategy, appropriate to the assessment of the impacts of climate change upon flood frequencies within an uncertainty framework, is introduced. The methodology couples a stochastic rainfall generator with the frequency version of TOPMODEL for the purposes of flood frequency estimation. Following constraint of *non-behavioural* rainfall realisations through the application of an observed/simulated sum of absolute errors criterion (based upon duration class annual maximum rainfalls), multiple realisations of potential annual maximum flood frequency curves are produced through the use of continuous simulation and Monte Carlo techniques. Further constraint of these realisations is then achieved via an observed/simulated flood peak sum of absolute errors measure, low flow conditioning, and calibration/validation for continuous rainfall/runoff modelling. Uncertainty in the flood frequency predictions is estimated using these *behavioural* realisations within the Generalised Likelihood Uncertainty Estimation (GLUE) framework. Example applications are provided for assumed "stationary" conditions.

REGIONAL INCREASE OF WINTER FLOODS IN SOUTHWEST GERMANY CAUSED BY ATMOSPHERIC CIRCULATION CHANGES

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Instationarity in the time series of annual peak flow will be demonstrated for the Enz River Basin/Black Forest (A = 1 477 km^2), the upper Danube (A = 1 320 km^2), and the Nahe River Basin (A = 2 382 km^2) in Southwest Germany. The reason for this is a dramatically increase in frequency and persistence of the large scale atmospheric circulation type "West cyclonic" (Wz) for the wintermonths (Dec.-Feb.). During the observation period (1926-1997) nearly all extreme floods including the floods of Feb. 1990, Dec. 1993, and Jan. 1995 for all three Basins have been caused by weather type "Wz" during winter. Nonparametric tests show that instationarity starts for the winter-Wz-frequencies and the annual peak flows of the ENZ River, the Nahe River, and the upper Danube Basin in the period of 1972 -1977. By this a shift to an increased flood risk will be demonstrated for the three river basins. Instationarity of the peakflows is caused by a significant increase of winter precipitation which itself is caused by changes of the atmospheric circulation. This leads to the HYPOTHESIS: "If the frequency and persistence of the circulation type "Wz" will become stabilised on the actual high level, many river basins in hilly regions of Southwest Germany will have a dramatically increased flood risk." Instationarity does not concern all Germany, but it is a serious regional problem for many river basins of Southwest Germany

The influence of the local catastrophical phenomena in the atmosphere.

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It is well-know that the concentration of the harmful substances in the atmosphere sharply changes during catastrophical phenomena which results in the further alteration of the regional and then global climate. Due to such phenomena as shower- type precipitations, intence rains heavy showing, the atmosphere clears from the harmful substances but at the same time there is a peculiar pollution of the soil, rivers, lakes and then seas and the oceans in the given region. Strong winds which disperse harmful substancesfrom the given region ovev the large territories are also of great importance. In order to study the given problem statistical data of the meteorological valuea for the last 15 years on the territory of Georgia will be analysed using 30 meteorological station.

COMPARISON OF FLOOD FREQUENCY MODELS BASED ON EXTREME RAINFALL ANALYSIS

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Flood frequency analysis often copes with scarcity of hydrometrical data. The use of the whole available hydrological information, both floods and rainfalls recorded in a large homogeneous area around the examined basin, improves design flood estimation. Parametrical methods of identifying these areas have some attraction but could give bad results. Moving from the index flood method, a hierarchical regional approach, employed in the Italian VAPI flood evaluation project, gathers all the extreme hydrological series belonging to an homogeneous area, whose extension depends on the order of an appropriate statistics. Particularly TCEV distribution, employed in this procedure, performs daily rainfall analysis for the identification of homogeneous hydrometric regions and subregions. Moreover hourly rainfall analysis is performed for index flood relationships. The growth curves so obtained are robust enough but attention must pe paid essentially to the regional estimation of index flood. Another interesting approach exploits pluviometric information for flood distribution by assuming rainfall excess fully transformed in runoff volume. This procedure, performed by the French AGREGEE model, fits directly local flood data in lower return period domain. For higher return periods it derives the slope (gradex) of flood distribution from the distribution slope of extreme daily rainfall recorded in a representative site of the basin. The choose of this pluviometric site and the threshold of rainfall data computed for flood gradex estimation are some of the peculiar steps of the procedure. Both AGREGEE and TCEV models assume different behaviour of the flood's CDF for low and high return periods. A more detailed comparison arise from the application of the models on various European hydrological data base.

REGIONAL GEOSTATISTICAL ANALYSIS OF VERY EXTREME RAINFALL AND FLOODS

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Natural hydrometeorological disasters in the Mediterranean region are generated in the past essentially by outlying events characterized by extremely large rainfall intensity and rare occurrence. Because of their rare occurrence, these extreme events can be treated only on regional frequency bases, to reduce parameter uncertainties estimation in gauged sites, and for risk evaluation in ungauged sites. A statistical regional model includes (i) a probabilistic model, which can explain the extraordinarily high rainfall and floods observed in the past; (ii) a regionalization model, which can take into account the observed spatial variability of the statistical parameter of the probabilistic model. Here, a regionalization model is shown, based on TCEV distribution probabilisti model, with a geostatistical analysis of its parameters. The regional model considers that the observed variance comes from two sources: sampling variability, due to uncertainties into point estimates, and spatial variability, due to effective difference between sites. Usual geostatistical techniques refe to the exactitude property in gauged sites. At-site estimates are affected by sampling uncertainty, that can be predominant for high order parameters. An iterative procedure is implemented, which allows to obtain the spatial structure of the noiseless variate. First results are shown, with reference to a case study for an Italian region. The objective differentiation between areas with different risk is one of the most important finding of the proposed regionalization procedure.

ANALYSIS OF THE METEOROLOGICAL PATTERNS PRODUCING FLASH FLOOD IN THE IBERIAN PENINSULA

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During October and November 1997, more than twenty people died in the Iberian Peninsula as a result of flash flood. This situation repeats every year. The meteorological patterns that produced the intense rain that resulted in flash flood differ widely. Very intense synoptic patterns like front or cutt-off-lows, mesoescale convective systems or even intense storms can produce flash flood. In this study we analyze the meteorological patterns producing flash flood in the Iberian Peninsula in the last ten years.

SCALING OF REGIONAL FLOODS - AN L-MOMENTS APPROACH

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An approach to analyse scaling properties of floods from expected order statistics and L-moments is here developed further with respect to the procedures for determining scale coefficients. A scaling relation has been introduced for the expected order statistics, which allows the derivation of a scale dependence of L-moments, L-moments ratios and of parameters of theoretical distribution functions. The method used to estimate the scale coefficients has a significant influence on the behaviour of the tails of the scaling relation. The effect of this is illustrated on scale dependencies for the GEV distribution, with the EV1 as a special case, applied to a Swiss data set consisting of 182 observation series with at least 20 years of instantaneous floods.

INCREASING FLOODING RISK CONSIDERING SEDIMENTATION IN THE RESERVOIR

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Reservoirs not only trap the incoming sediment load but also reservoir sedimentation increases the flooding risks because of aggravation upstream of the reservoir. Reservoir sedimentation results in loss of storage capacity for flood control and/or water supply. Sedimentation in reservoirs is a random variable and the value of sediment coming to the reservoir and/or passing the outlet, should be considered as a random variable. In the study a probability distribution function was found for the accumulated sediment in the a reservoir. Therefore the value of accumulated sediment for any year during the life time of reservoir was estimated. Accordingly with considering the initial reservoir capacity, the capacity of the reservoir was estimated for any year after the construction of the reservoir. Obviously the reservoir capacity is decreasing. Applying the Moran's Model for reservoir sizing considering the dependence of reservoir capacity with time, the probability of overflow for every year after construction of the reservoir was obtained. The results of the study shows how the risk of flooding in downstream of the reservoir is increases during the life time of a reservoir.

REGIONALIZATION OF THE EXTREME ANNUAL RAINFALL USING THE TWO-COMPONENT EXTREME VALUE MODEL : DISCUSSION AND APPLICATION

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This paper presents the regionalization method of maximum rainfall based on the cumulative distribution function (CDF) of the Two-Component Extreme Value (TCEV), developed by Rossi et al (1984) and its application on the daily maximum annual rainfall samples over the region of Minas Gerais (Brazil). This statistical model is based on the product of two exponentials, both representing a Poisson process: the first corresponding to the most frequently maximum rainfall generated and the other corresponding to the outliers . Theoretical aspects of the model are briefly presented and discussed. The regionalisation technique is divided in two parts.The first regionalisation level consists in defining the homogeneous regions.. Working with dimensionless values, the data of the homogeneous regions are pooled together to give a single series of station-year. The second regionalisation level consists in defining sub-regions where the third paremeters of the cumulative distribution function TCEV are constant. The procedure used is a first step to define hydrological homogeneous regions related to the flood frequency studies.

NH2 Meteorological and hydrological hazards (woint with HS)

04 Modelling and flood mapping in rural and urban areas

Convener: Oberlin, G.
Co-Convener: Roth, G.

Sponsorship: EC/DG XII/Natural Hazard Section, CEMAGREF

USE OF WEATHER RADAR FOR THE MONITORING OF COMBINED SEWER OVERFLOWS IN BARCELONA AREA.

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In Mediterranean region, climatological factors make combined sewer overflows a major urban pollution problem that should be monitored and controlled. Some on line management solutions require the use of real-time models to forecast flows at the most sensitive points of the combined sewer systems. These models need high spatial and temporal resolution of the rainfall field that are not sufficiently reproduced by a conventional rain gauge network. Weather radar is introduced as a very useful tool for reproduce the spatial fields. This paper presents a case study where the use of rainfall estimates from radar images is compared against the use of a raingauge network in terms of the ability to predict sewer flows in an urban basin located in Barcelona. The results show that the use of radar data enables the combined sewer system model to improve the reproduction of observed flows, and they provide support for the idea that the spatial description of rainfall is a key problem in modelling events giving rise to combined sewer overflows.

MODELLING THE MAXIMUM PROBABLE FLOOD IN A LARGE ROMANIAN RIVER

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In modelling the probable maximum flood (MPF) a deterministic method was used, based on the integration of the probable maximum precipitation (PMP) by means of the rainfall-runoff model.
The quantity, distribution on time and space are determined from the genetic procedures which are based on the maximisation of the some observed extraordinary rainfalls.
The rainfall-runoff model simulate the following components: the mean inflow, effective rainfall and the total flow on each sub-basin, the composition of the flood waves and their routing within the channel.
Finally, some aspects of the affected area are presented, as well as the change of the parameters of routing of flood.

MAPPING OF FLOOD PLAINS. THE CASE OF THE SESIA RIVER

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The Piemonte Region, within its institutional competencies regarding natural risk forecast and prevention, is experimenting a real-time flood forecasting system, aimed to civil protection. This system is made up by an operative structure that carries out forewarning operations, by an hydraulic-hydrologic model that allows flood forecasting and by a flood risk analysis that leads to emergency planning management.
This poster shows a method for flood risk assessment and its application to the Sesia River (left tributary of Po River). An analysis of main flood events involving Sesia River, occurred in the past fifty years (1954,1968,1977,1993,1994) has been performed in this view through air photography, historical sources, and field surveying studies. Moreover an hydraulic model that leads to flood forecasting has been used to define free boards in crossing and defence building, with reference to several different floods. Finally, all these studies allowed to recognise the most vulnerable areas close to the river, outlining both the main flood flow zone in a significant event (1993) and the lateral zone at its sides at flood risk in case of events characterised by flows comparable to those measured in November 1968.

FLOOD PLAIN ZONING ON HEADWATER

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Flood plain zoning is a well known non-structural measure and also a powerful tool in different aspects of the flood protection management. We should extract on flooded area: flood way, area flooded by ten years return period flood, area flooded by hundred year return period flood and area flooded by maximum probable flood. On headwater streams we suggest that river bank erosion and sediment deposition should be incorporated into the zoning. A few hours of inundation can not damage a structure as much as soil and river bank erosion can. Also sediment transport could completely change hydraulics conditions on flooded area. Potential erosion can be estimated by hydraulic and sediment transport models, geological data, and using experience with previous floods.
The most important characteristics of a flood for flood protection are the time lag from the beginning of rainfall to the peak discharge, the time duration of the flood wave, and the maximum velocity of the rise of water level.

ESTIMATING EXTREME DISCHARGE VALUES OF SMALL WATER COURSES IN TRANSDANUBIA/HUNGARY

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On the basis of discharge data at 51 reliable gauging stations in the mountainous and hilly region of Transdanubia/Hungary (29,000 km^2), simple empirical formulae and graphical methods have been developed in order to estimate critical extreme discharges for ungauged stream sections in catchment areas between 30 and 3000 km^2.

For estimating the flood discharge $HQ_{3\%}$ of three per cent exceedance probability, three different methods have been used:
(a) Assuming the validity of Csermák's formula, $HQ_{3\%} = B_{3\%} \cdot A_E^{0,5}$, the isoline map of the flood discharge coefficient $B_{3\%}$ has been updated by using observation data of three decades.
(b) In the generalized form the exponent n is treated as a free variable: $HQ_{3\%} = C_{3\%} \cdot A_E^n$. For each of the seven subregions in Transdanubia, the optimum value of the parameters $C_{3\%}$ and n has been determined.
(c) Likewise in a grouping according to subregions a relationship between the quotient from flood discharge and mean discharge, and the catchment size A_E has been established.

On the basis of a comparison of the results obtained by using these three empirical methods, it is recommended to use Csermák's formula preferentially in the future as well, taking the revised isoline map of the coefficient $B_{3\%}$ into consideration.

In Hungarian water resources management the channel forming low discharge Q_m is interpreted as the discharge pertinent to the point of inflection of the flow duration curve. For its estimation an empirical relationship has been used yielding the quotient from Q_m and the mean discharge as a function of the catchment size A_E for the total area of Transdanubia.

THE EXPERIENCE OF THE LIGURIA REGION IN THE EXTREME EVENTS MANAGEMENT.

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In the past years many efforts have been spent in research for the realisation of reliable systems for flood prediction. The final purpose of this work is an enough early and efficient communication of the flood warning. Very often the research results in meteorological and hydrological prediction are cancelled by the weak link of the chain: the information transfer from the scientific community to ordinary people. In the past few years in Italy the Liguria Region attempted to produce an efficient system for flood prediction, exploiting the most recent results in atmospherical and rainfall runoff modelling, and able to transfer, in the most efficient way, the meteo-hydrological warnings to population living in regions characterised by a complex horography. Rainfall and meteorological fields produced by a high-resolution Limited Area model are analysed in order to define the basin classes for which the conditions are potentially hazardous. A discharge classification allows to link the water level in the river with a risk level and different actions to undertake. Once hazardous conditions has been noticed, warnings containing the risk level for each basin class are sent to local authorities. All these knowledges, described before, represent a real help to briefly transfer a clear message to the population, allowing a simple and efficient management of the flood risk.

MAPPING FLOOD PLAINS FOR A BETTER RIVER MANAGEMENT

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Within the Floodaware European project, we propose a new flood plain management method based on the comparison of hydraulic information with land use information. The use and crossing of distinct information layers (of hydraulic, topographical and geographical type) argue for the use of a G.I.S. (Geographical Information System). However, in order to avoid the addition of a G.I.S. which is a complex and heavy tool, dealing with a large amount of complex data, to other essential software such as the topographical and hydraulic numerical models, we consider that a global geomatics model, having all the needed functions (from the flood management point of view), including the typical ones of the G.I.S., should be developed. The G.I.S. concepts and functions we propose are well enough in agreement with the map-making process of the flood plain management, but the current G.I.S. implementations require the development of complex interfaces which have to take into account the topographical and hydraulic tools used in this field. A better solution is to identify and to define a single type of basic geometrical object from the set of geometrical, geographical and hydraulic constraints. In this way, a single topographical data base is built, on which all main functions of G.I.S. are developed. These functions are integrated into the different cartographic and hydraulic modules, used to simulate the river flows.

THE NATURAL RISK SITUATION HALL

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The natural risk situation hall is an operative service, where all the environmental data measured by the regional network of ground stations (about automatic 160 stations, plus about 50 snow manual stations) and other non conventional data are collected (satellite and radar images, seismic network maps). All measurements are acquired in real time, with a maximum delay of 10 minutes. The measures related to the precipitation and river levels are directly comparable with the data observed during the past floods. A centralised informative system was initially set up to standardise the different messages and observed data and to manage them with homogeneous tools. Afterwards a monitoring system, operative for 24h /day, was implemented to follow the effects of heavy rain or snow precipitation hazardous events in the Piedmont Region. Some procedures turn the raw observed data into recommendations and messages for the authorised people devoted to alarm in case of extreme meteorological and hydrological events. The staff also perform statistical elaboration of the data, dissemination to a large set of users of scheduled and exceptional bulletins, regarding the meteorological situation and its forecast, snow and avalanches danger, hydrologic alarms, seismic activity on the region. The information delivery is carried out by fax, by telematic distribution (e-mail, internet, special connections); a telephone service is up to date every day. A very complex informative system supports the operative structure making available a data base that collects and archives all the data. Also display tools are studied on purpose to allow a friendly fruition of heterogeneous data.

THE EFFECTS OF FLOODPLAINS ON FLOODWAVES: AN ANALYSIS AND COMPARISON OF DIFFERENT MODELING TOOLS

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In the aftermath of the floods of 1993 and 1995 on the Nahe River in Germany, questions were raised on the effects of floodplains on downstream flooding. As a result, mathematical simulation tools of varying complexities were tested and utilized in order to develop a simple method to quickly estimate floodplain retention properties. A parametric technique that modeled the flows in the main channel and the floodplains separately through a diffusion wave approximation was first applied. Although this simplified method used only channel properties averaged over entire reaches and was known to over-estimate floodplain retention, it provided a good general estimate of the influences of the floodplains and could be applied quickly. It was found that for the Nahe River, the floodplains provide negligible retention for floods with the volumes associated with the 1993 and 1995 events. For events of smaller duration and magnitude, thus lesser volume, the retaining capacities of the floodplains are greater. A 1-dimensional unsteady flow (full dynamic wave) model was then applied. This yielded the same conclusions as the simplified parametric method, but also provided more accurate quantitative results. A simpler 1-dimensional model, which modeled the floodplains and the main channel separately through the Muskingum-Cunge routing method, yielded similar results to the unsteady flow model. At the highest degree of complexity, 2-dimensional dynamic wave modeling provided more understanding into the reasons behind the lack of floodplain retention in the Nahe River. It could be seen that once there was an appreciable volume of water in the floodplains, it began flowing, thus transforming the floodplains into a moving body of water. Often, this flow would short-cut river meanders. Thus, although the water in the floodplains flowed slower, it traveled a shorter distance, thus arriving downstream at approximately the same time as the floodwave in the main channel. The 2-dimensional model was also found to be advantageous in its ability to delineate the physical extent of flooding.

CALIBRATION OF A RAINFALL-RUNOFF MODEL USED IN FLOOD FREQUENCY ESTIMATION

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The calibration of a conceptual rainfall-runoff model, the Probability Distributed Model (PDM), is described in the specific context of comparing flood frequencies estimated from simulated and measured flows. To reduce the dimensionality of the calibration problem, routing store parameters were first established by recession curve analysis. A Monte Carlo procedure was then used to search for parameter sets that best reproduced observed flow data, where goodness-of-fit was assessed via four objective functions, designed to give different degrees of weight to peaks in the flow time series. Examples are shown of the results of the numerical procedure, and of the benefit of manual parameter adjustment to improve the 'simulated' flood frequency distributions in some cases. Results confirm that the primary aim, to achieve good flood peak predictions, is best served by using an objective function strongly weighted towards peak flows. However, other aspects of the flow regime are also considered, as confidence in the modelling approach will be greatest when these are reproduced well. Finally, multivariate sensitivity analysis shows that there may be many possible acceptable sets of parameters, for any given measure of fit. Checks of flow duration curves may be useful in discriminating between these alternative calibrations.

EFFECTS OF RAINFALL DATA QUALITY ON FLOOD FREQUENCIES IN SIMULATED STREAMFLOW

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Flood frequencies can be estimated by analysis of simulated flow data, generated using a conceptual rainfall-runoff model. This approach to flood estimation, which is now receiving increasing attention as an alternative to event-based methods, avoids the problem of specifying antecedent conditions for a design event. Also avoided is the need to specify individual design storm depths, durations, profiles and return periods. Instead, measured or synthetic rainfall time series are treated as a continuous input. The potential effects of rainfall data quality are therefore an important concern, which is addressed in this paper. Flood frequency estimates derived from simulated flows will be presented for three contrasting catchments in the UK (one upland/rural, one urbanised and one with a permeable geology). In each case, recorded hourly rainfall and flow data have been obtained for long periods to allow calibration of the PDM rainfall-runoff model, with strict quality control procedures being applied to the rainfall data. Flood estimates from the simulated and measured flows are compared using peaks-over-threshold analysis. A common problem that may affect the flood frequency estimates is the presence of gaps in autographic raingauge records, which can be addressed using an in-filling technique. In-filled gaps were inserted at increasing frequencies into the quality-controlled hourly rainfall data to investigate the effects of reductions in rainfall quality, and comparisons made across the three catchments.

Model and Spatial Database to Assess Design Peak Flow Rates in the Walloon Region (Belgium)

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Managing and planning rural catchments require the setting up of efficient hydrologic tools. To this end, the Unité d'Hydraulique Agricole of the Faculté Universitaire des Sciences Agronomiques de Gembloux has combined a Geographic Information System, covering the whole Walloon Region, with the hydrologic model SWRRB-WQ, adapted to the Belgian conditions.
Associating the model with the GIS provide us with geomorpho-hydrologic information, spatially distributed on the studied basins, as well as design flow rates and daily flow rates. Let us underline that soil moisture is one of the variables of the model SWRRB-WQ and that it has an influence on the runoff rate, through a digital parameter : CN (curve number). The latter comes from the method used by the American Soil Conservation Service (SCS). Using the geographic database together with the model allows us to carry out a regional analysis which is linked to the catchment planning.
Examples of simulation analyses show the effects of Karstic areas and the links between sub-bassins.

CONVECTIVE RAINFALL MAPPING AND THEIR RELATIONSHIP WITH FLOODS IN CATALONIA (SPAIN)

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The main floods events produced in the West Mediterranean Area are related with high intensity rainfalls associated with convective systems. For this reason the identification between convective rainfall and high intensity rainfall is very usual, although it is not always correct. After considerating the different points of view, the authors have proposed a new parameter, β^*, which allows classify the rainfall events between non-convectives, moderately convectives or highly convectives, in basis to the 5-minutes intensity. This parameter has been previously analysed using the long rainfall rate series 1928-1981 of Barcelona. However, the objective of this paper is to show the application of this parameter as an index of the spatial convective distribution in Catalonia. This mapping has been made using the 5-minutes rainfall data from the SAIH (Automatic System of Hydrological Information) of the Internal Basins of Catalonia for the 1996 year. This system allows to have information in real-time of 125 raingauges covering an area of 16000 km^2. The 1996 year was characterizated by the extraordinary number of pluviometric events and floods along all the year. These results have been compared with the mapping made using a climatic parameter β and 30 years of monthly data. Finally, a conection between the damage events in the last years, the distribution of this parameter and the rainfall intensities have been made in order to estimate the main flood prone areas and to identificate the events with flood risk.

FLOOD MODEL VALIDATION USING SAR IMAGERY

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2-dimensional finite element hydraulic models of floodplain flow have previously only been validated and calibrated against point hydrometric data, whereas the distributed nature of the models is more compatible with validation against distributed data. Flood maps derived from satellite SAR imagery via a semi-automatic image processing scheme are used to calibrate floodplain friction coefficients of a 2-D hydraulic model of a 14km reach of the river Thames, UK. Issues such as assimilation of topographic information and the associated errors in model predictions are addressed, in order to direct future surveying and modelling strategies. As more validation data becomes available, validation and calibration against SAR derived flood maps will enhance the predictive capability of these flood flow models.

AN INTEGRATED SYSTEM FOR MONITORING AND EMERGENCY MANAGEMENT OF FLOODS

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The need of hydrological modelling supported by well-developed monitoring systems appears more and more essential in the light of flood events occurred over the world in the last decade. Simulation models can be considered as preventive tools for flood hazard and risk evaluation. Only their integration with real time monitoring system lets solve those "rapid" problems regarding the assessment of the general flood situation and identify areas at greatest risk and in need of immediate assistance.
In this paper an integrated real time flood forecasting system realised on an urbanised basin in southern Italy, frequently interested by extreme flood events, is described.
The system is developed in four main modules, respectively: of acquisition and analysis of the real time rain and water level information given by the telemetering gauges; of calibration of the parameters of the rainfall-runoff transformation model; of forecasting of future rainfall based on stochastic point model; of simulation (deterministic and stochastic) of flood levels at critical points of the basin.
Such modules are integrated within the system with the aim of guaranteeing a continuous procedure between hydrological information directly measured on the basin and that ones obtained through forecasting procedures.

INUNDATION MODEL FOR FLOODPLAIN ANALYSIS

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The paper describes the use of a two dimensional unsteady flow hydraulic model that implements the complete De Saint Venant equation for floodplain simulation. Aim of the work is to investigates flood inundation due to overtopping or break of levees accounting for the presence, in the inundated plan, of banks (like streets and railways) and of a network of drainage channel.
Simulation of hypothetical and one real floodplain illustrates the potentiality of the model to account for the microtopography, changes in the roughness coefficient and presence of urbanized areas.
Such a model is usefull for planning and civil protections plans.

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USING GIS AND AERIAL PHOTOGRAPHS TO DETERMINE THE WATER LEVELS DURING FLOOD

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To map water levels in case of large floods, it is proposed to manage by GIS the great number of information extracted from aerial photographs. Our method is developed in 3 points: 1) segmentation of the flood plain in sectors with acceptable mean water depth, based on geographical limits and size criteria. 2) determination of minimum and maximum depth for each sector, based on the emergence or not of natural objets (vegetation, dikes ...). 3) amelioration of the estimation of the water depths, using all observed hydraulic connections between sectors (cracked dikes, flows ...). This amelioration is done solving a constraint system linking the different water levels estimated in 2). Application concerns Herault River for the November 1994 flood, with aerial photographs taken 6 hours after the maximum of flood. Results give good determination about water levels, the lateral dynamic behaviour of flood (1,5 m of difference in levels between centre and edges of plain), and the impact of dikes. These results are obtained without introducing neither general hydraulic equation nor local head losses coefficient. The great number of fuzzy information, compensate for the low quality of each one.

URBAN DEVELOPMENT AND FLOOD HAZARD

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Flash floods are a typical feature of the southern Europe Mediterranean coastline: they designed the morphology of the terminal floodplains of the many small and medium size torrents dissecting the rugged orography of the Mediterranean slopes of the Pirineos, Alpes Maritimes and Appennines. The urban development of the floodplains, staring from the Roman Empire colonization, was definitely unaware of the flood processes: the braided rivers used to drain during the flood season the alluvial plains were trained to a unicursal bed all along the Mediterranean arch. A few examples are presented, from the Middle Age to the present, of the urban development leading to the present high frequency of disastrous events. The effect of the railway extension along the coastline during the past century is analyzed. The expansion of coastal cities in the present century on the northern arch and their explosive growth in last decades in the eastern part, in Turkey and Syria, created the conditions of making the flash flood hazard one of the most demanding all along the Mediterranean coastline.

Organic matter content in soil results from the balance among primary productivity and leaflitter production, leaflitter decomposition, and abduction by rainfall events. The loss of wooded areas because of unwise management or natural accidents can condition this balance. Fires are particularly effective in causing vegetation destruction and soil exposure; moreover fires have some marked effects on physico-chemical characteristics of soil, since destroying organic matter in surface layers they alter permeability, porosity, aggregate stability and then erodibility of hillslopes. Surface runoff is also increased. Burnt areas of a small Ligurian river basin were identified over a period of 15 years, from 1982 to 1996. Recovery rate of vegetation cover and restoration of the original organic content and then of biotic control over erodibility in burnt areas were evaluated at the local scale. Decomposition tests and collection of leaves by traps to measure leaflitter production were also performed. Experimental evidence suggests that non-linear interaction between forest fire processes and extreme rainfall processes in small semiarid Mediterranean watersheds could leave to irreversible local desertification conditions.

DELFT FLOODING SYSTEM: TWO-DIMENSIONAL HYDRODYNAMIC FLOODING SIMULATION. A POWERFUL TOOL FOR LANDSCAPE PLANNING AND RISK EVALUATION

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The at Delft Hydraulics recently developed 2D-hydrodynamics prediction package Delft-FLS, is specially suited to simulate the dynamic behaviour of overland flow over initially dry land, the influence of existing or future infrastructure, as well as flooding and drying processes on every kind of geometry, including lowlands and mountain areas. A robust numerical scheme allows for the correct simulation of sub-critical and supercritical flow. Internal boundary conditions are included to simulate dam-break / dike-break events. It can be coupled to a one-dimensional model in order to give more details where needed, speed computations and facilitate the study of flood events on natural river basins, polders, channel-networked regions and urban areas. This package provides a reliable prediction of the hydrodynamics of flooding events extremely necessary when dealing with disaster management, evacuation plans and flooding damage assessment. These predictions can be also used during landscape, infrastructure and urban planning phases as well.

ESTIMATION OF FLOOD PRONE AREAS IN A RIVER PLAIN BASED ON CONVENTIONAL AND LASER-SCAN DEVELOPED DIGITAL ELEVATION MODELS (DEM)

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Flood risk maps provide an overview of the areas threatened by possible flooding. The delineation of these at-risk areas is often a controversial issue. It was thus desired, through the testing of different methods, to develop a reliable tool for estimating the extent of possible flooding. This analysis was performed on the Nahe River (Rheinland-Pfalz, Germany), which experienced large floods in 1993 and 1995. A digital elevation model (DEM) with a 20 m horizontal resolution was already available for Rheinland-Pfalz. In addition to this, a short reach of the Nahe, between the villages of Martinstein and Sobernheim, was surveyed using an airplane-mounted laser scanner. This yielded a DEM with a 2 m horizontal resolution. Based on these two data sets, the first attempt to simulate the flooded areas from the 1995 event involved the utilization of a 2-dimensional unsteady flow model. As would be expected, the enormous quantity of data in the DEMs caused these simulations to be extremely time consuming. To develop a less time-intensive method to delineate flood-prone areas, two different planes representing the water surface elevations of the Nahe at a specific flow were created through the GRASS geographic information system (GIS). One was based on a constant water depth in the main channel at the upstream and downstream ends of the modeling reach, thus resulting in a plane of constant slope. The other plane was based on the flood simulation results of a 1-dimensional unsteady flow model. This provided a profile of water surface elevations throughout the reach, which was transformed into a non-constant plane. The areas under these two planes were considered to be flooded. In comparison to the 2-dimensional modeling, this method of overlaying previously computed water surface elevation planes on a DEM involved considerably less time and was easier to apply. The results of this method were comparable to those from the 2-dimensional model.

THE FLOODING PROBLEM OF SPERCHIOS RIVER BASIN (GREECE). A STUDY, USING THE NUMERICAL MODEL MIKE 11

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This work is an introduction to a procedure used for the numerical simulation of Sperchios river basin. In this procedure MIKE 11 model has been used, as the most reliable model in river modelling. The water management of Sperchios river basin requires a large number of measurements and prediction of future situations like flooding. This research contains collection and consideration of all available measurements and estimation of the water quantity of the river basin. In this paper a number of runs from Sperchios River hydrodynamics are presented and two different scenarios for better understanding and integrated management of flooding discharges are analysed. In the first scenario it was approved numerically that the existing channel is not able to receive the 50-year sequences discharges. The result is the flooding of the river basin. The simulation shows numerous points were construction has to be made, to safeguard the riverbanks. In the second scenario has been approved numerically that the current situation of Sperchios river network without any other construction, can solve the flooding problem of Sperchios.

NH2 Meteorological and hydrological hazards (joint with HS)

05 Shallow landslides and rainfall triggering

Convener: Sorriso-Valvo, M.
Co-Convener: Versace, P.

Sponsorship: CNR (Consiglio Nazionale delle Ricerche), Universita della Calabria

ROCKFALLS ON THE N1 HIGNWAY IN LA RÉUNION ISLAND (FRANCE) : HAZARD EVALUATION FROM RAINFALL

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The 12 km coastal N°1 highway in La Réunion (Indian Ocean) is frequently hit by rockfalls which cause many accidents. The road is located at the toe of a cliff, typically 150 m high, of alternating stratas of basalt and volcanic tuff. The blocky nature of the basalt and the erodability of the tuff result in numerous falls (about 100 a year), mostly triggered by rainstorms (annual precipitation : 1 to 2 m). More than four years of data (every two hours) are at our disposal : rainfall (three locations) and record of pieces of rocks found on the road by a dedicated team.
Different statistics about rockfall occurrence have been made : distribution according to the month, or the section of road, volume per event, etc. The correlation between rockfalls and precipitations is obvious when seen at a monthly scale, but is difficult to quantify at a daily scale. One could roughly say that only half of the falls are clearly related to rain events. Different thresholds of rainfall per day have been tested, combined with several time delays between a rain event and a rockfall. This kind of analysis can be used for a traffic regulation : the road can be partially closed to traffic when some precipitation criteria have been exceeded.

THE EFFECT OF LAND ABANDONMENT ON SOIL WATER REDISTRIBUTION AND PREFERENTIAL FLOWPATHS ON SHALLOW LANDSLIDE INITIATION.

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The occurrence of shallow landslides is a common process in the basin of the Riu Serpis (SE Spain). Because of the extent of the affected area, shallow landslides are the dominant form of hillslope erosion in this marly area and threaten the productivity of the bench-terraced agricultural lands and semi-natural slopes. The biological activity caused by the revegetation following abandonment results in an improved storage capacity of the topsoil. At the same time, the presence of macropores -preferential flow paths of water, possibly connected to shallow slide planes- shortens the response time of the soil mass to reach critical pore pressure conditions. Therefore, under given rainfall conditions, a larger area will be prone to landsliding after abandonment. This hypothesis that abandonment increases potential landslide activity, was investigated by rainfall simulations at locations with different land use conditions. Broad scale rainfall simulations with automated soil water dynamics monitoring (TDR) and tracer applications, and additional small scale experiments, were carried out on several terraces which were under culture or were abandoned for different periods. Infiltration patterns in the soil were measured, to study the heterogeneity in infiltration under plants and to study preferential flowpaths of water, which might be connected to shallow slide planes. Differences in general infiltration velocities were found under various types of vegetation, related to land-use history. On all plots with semi-natural vegetation, deep penetrating preferential flow along continuous macropore systems was observed and the heterogeneity of infiltration patterns and preferential flow paths were found to be more important on terraces which were longer abandoned.

ANALYSIS OF TOPOGRAPHIC CONTROL ON SHALLOW LANDSLIDING USING A QUASI-DYNAMIC WETNESS

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A model for the analysis of topographic influence on shallow landslide initiation is developed and applied to a mountain experimental basin where high-resolution digital elevation data are available: the Cordon catchment (5 km^2), in north-eastern Italy. The model builds upon a theory for coupled shallow subsurface flow and landsliding of the soil mantle previously proposed by Montgomery and Dietrich (1994). The model uses a 'quasi-dynamic' wetness index to predict the spatial distribution of soil saturation in response to a rainfall of specified duration. The rainfall predicted to cause instability in each topographic element is characterised by duration and frequency of occurrence. This provides a practical way to identify the relative potential for shallow landsliding. Furthermore, this approach provides a theoretical link between methods based on intensity-duration thresholds and explicit, physically-based models of slope instability. An inventory of landslide scars is used to document sites of instability and to provide a test of model performance by comparing observed landslide locations with model predictions. It is found that the model reasonably reproduces the observed distribution of landslide locations, although spatial variability of soil properties and hydrologic complexities not accounted for by the model complicate prediction of where landslides occur within areas of similar topographic control.

REGOLITH EVOLUTION AND THE CONTROL OF SHALLOW TRANSLATIONAL HILLSLOPE FAILURE : USE OF A 2-DIMENSIONAL COUPLED SOIL HYDROLOGY-SLOPE STABILITY MODEL

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Recent advances in physically-based modelling now enable highly detailed investigation of hydrological conditions at the time of failure, particularly for shallow translational failure. Modelling is a non-invasive technique and provided adequate parameterisation and validation data are available it is possible to apply the 2-dimensional coupled soil hydrology-slope stability model to a variety of research problems. Available models produce high resolution information in both time and space, enabling detailed rainstorm data to be included for soil profiles which are highly differentiated in terms of geotechnical and hydrological behaviour. One of the main advances has been in investigating the ways in which temporal evolution of regolith over Holocene timescales has altered the probability of shallow translational failure. In New Zealand slopes have been stable during much of the early part of the Holocene. Recent anthropogenic activity, mainly involving deforestation, has resulted in a phase of progressive regolith stripping. Following initial failures in which about 25 percent of the regolith is stripped from the slope, it has been suggested that the removal of the remainder is somewhat more difficult as thresholds for instability rise. However, extreme rainstorms are still capable of initiating slope failure. A phase of reduced stability then occurs as regolith is redeposited at the slope base, having modified hydrological and geotechnical behaviour. Application of physically-based models to this sequence of regolith stripping and evolution has broadly supported these conclusions. Importantly, model results have also permitted identification of appropriate climatic thresholds for slope failure for these different phases, and have shown how the hydrological controls on slope instability have altered over time.

HAZARD ASSESSMENT FOR RAINFALL-TRIGGERED LANDSLIDES

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Hazard and risk assessment for landslides may be carried out in a number of ways. The selected procedure may include formal analytical approaches, deterministic or probabilistic. However, less formal approaches, often used in practice, include considerable reliance on experience and engineering judgment. This paper is concerned with aspects of assessment based on observational procedures and data. Attention is devoted to the main hazard and risk requirements for the development of such procedures.

Historical records of landslide activation and reactivation may be available in some areas along with rainfall records. From such information and data the past frequency of landsliding can be assessed and conclusions can be drawn about the expected probability of landsliding in a temporal sense. However, such information is often limited and subject to significant uncertainties.

A modern approach based on observations at instrumented sites can be more useful and reliable in estimating the hazard of rainfall-triggered landsliding. Data from inclinometers and piezometers can be related to rainfall data. Periods of Peak subsurface shear movement as well as accelerating shear movement can be identified. Recently an innovative approach has been developed to study the relationship between antecedent rainfall and significant episodes or periods of shear movement. The most significant antecedent rainfall period for a particular area or region can be assessed from such studies. The method has proved very useful for shallow landslides which are often self-stabilising in character. The method also has potential for study of rainfall-triggered debris flows.

EVENT-INDUCED CHANGES TO LANDSLIDE TRIGGERING THRESHOLDS

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Rainstorm-triggered landslide events alter terrain conditions sufficiently to affect susceptibility to future landsliding. In one hill country catchment changes to inherent resistance (measured by the factor-of-safety) resulting from a major event indicate , in future, small triggering rainstorms would be more affective in producing landslides while moderate to large storms would be less affective. The mechanisms responsible for changes in inherent resistance include mass movement induced redistribution of regolith, changes to regolith properties, changes in regolith depth and the development of unsupported erosional scarps. The influence of these mechanisms on susceptibility of typical slopes has been investigated and quantified by the use of a combined hydrological slope stability computer simulation model. The net effect is expressed in terms of time to failure and total rainfall required to trigger movement.

A CELLULAR AUTOMATA MODEL OF THROUGH FLOW IN A POROUS SOIL FOR SHALLOW LANDSLIDE FORECASTING

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Parallel computing models represent a valid alternative to standard methods with differential equations in modelling complex phenomena. Cellular Automata (CA), a paradigm of parallel computing, permits such an alternative approach for modelling and simulating complex systems, whose evolution can be described in terms of local interactions of their constituent parts. When the basic laws of continuum mechanics cannot be directly applied without adding phenomenological assumptions, and the equation systems are not amenable to analytical solution, direct discrete modelling may represent a convenient alternative to the use of continuum models, followed by numerical discretisation. Water infiltration on a soil can be viewed as a phenomenon based on local interactions; the equation governing the flow cannot be easily solved without making substantial simplifications. Particular complexity arises for the soil composition and irregular ground topography. In this paper we describe a macroscopic CA model for simulating the water infiltration in a 2-layer slope model. The model assumes the upper layer of the soil as initially non-saturated and inhomogeneous, while the lower layer is impermeable. It describes the water infiltration and groundwater retention. Transformation of water storage into neutral pressure requires an ancillary computation code. Applications are performed on an ideal slope using different rainfall intensity and duration.

NUMERICAL SIMULATION OF FLOW LANDSLIDES

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05 Shallow landslides and rainfall triggering

Flow landslides which get formed as a result of intensive precipitation constitute slope deformations in the form of viscous-plastic ground flow. For the numerical simulation of flow landslides movement a hydraulic model was used which before had been successfully used to describe snow avalanches and mud flows. In the mathematical model of the flow landslides use was made of specified relations which describe friction of soils and portray the peculiarities of the landslides movement. The numerical simulation of the flow landslides movement allows one to calculate the speed and the speed vector direction of the landslides at any point of the slope and to obtain the configuration of the landslides tongue in the plan and at arbitrary moment of time.

MODELLING AND TRIGGER MECHANISMS OF SOIL SLIPS

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The available studies concerning soil slips triggered by critical rainfalls, in addition to a complex picture of knowledges, they point out that these surficial slope failures frequently determine unacceptable risk thresholds. As regards the spatial forecast, whereas it is clear the role of some predisposing factors (slope angles, cover thickness, etc.), to others (local variation of the pluviometric input, geotechnical parameters, etc.) the knowledge picture is less clear. Relatively to temporal forecast, are sufficiently consolidated some indications relative to the characteristics of the rain able to trigger shallow failures in the slopes; less clear are, on the contrary, the relationships between local and mean characteristics of the rainfall events. Therefore, as regards the mechanisms that govern soil slips initiation, the pluviometric conditions can play a double role: factor of trigger, factor that predispose the location. It follows the importance of the models that simulate the infiltration process of the rains into the shallow layers of soil, and the suitability to verify their potentialities. This type of investigation is carried out referring to some simple geotechnical schemes, inferred from the literature, and to some of the utilizable calculus codes. In particular, referring to the same pluviometric input and to the same physical parameters of the soil, it is shown the influence of the calculus codes in the evaluation of the pore pressures distribution in the upper layers of soil. Then, referring to a specific calculus code, it is shown the variation of the pore pressures distribution in relationship to rainfall conditions and physical parameters of the soils. Finally, the results altogether achieved allow to outline a possible methodological approach for the study of the soil slips, and they point out some searches necessary to typify contexts geo-environmental homogeneous with respect to the considered instabilities.

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Debris avalanches, or open-slope debris flows, are extremely rapid catastrophic landslides which are triggered by heavy rains. Long triangular scars are commonly observed on aerial photographs of British Columbia forested steeplands on both logged and unlogged slopes. Since 1956 numerous debris avalanches have been documented on steep mountain slopes in British Columbia wher they have caused a number of deaths as well as substantial damage to property and the forestry resource. Debris avalanches can occur on slopes where there is no evidence of previous instability. Landslide volumes are generally the range 20,000 - 60,000 cu. m. Debris avalanche paths may exceed 500 m in length but involve only a very thin veneer (less than 2 m) of surficial materials. Based on eye witness accounts, the velocity of debris avalanches commonly exceed 10 m/s. A dynamic analysis of the 1990 Belgo Creek debris avalanche (estimated volume 23,000 cu. m) event indicated local velocities of as much as 20 m/s. Undrained loading may be an important mechanism in the development of debris avalanches and contribute to their high velocity. The behavior and occurrence of debris avalanches is to be contrasted with channelised debris flows which are generally recurrent in a given watershed and in which the velocity rarely exceeds 7 - 8 m/s.

FEEDBACK EFFECTS OF RAINFALL-TRIGGERED SHALLOW LANDSLIDING

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Rainfall triggered landsliding is a common and widespread phenomenon in New Zealand, following extensive deforestation within the last century. Spatial variation in the relationship between rainfall and erosional response is recognised for a number of regions. However, the rainfall/erosional response relationship established for a given region shows a tendency for temporal variation. This variation can be attributed to mechanisms described as "ambient filters" and "event resistance", which operate as a result of successive landsliding episodes.
This temporal variation in susceptibility to landsliding has been investigated by comparing the stability conditions of a catchment on two historical occasions 23 years apart. Changes in relative susceptibility are interpreted as an alteration in the relationship between rainfall input and landslide response. A refined process model for landslide occurrence is presented, incorporating feedback loops resulting from the occurrence of the landsliding process. Results are also used for an initial calibration of a proposed model of landform relaxation. This model describes the development of and changes in catchment susceptibility to landsliding following significant environmental change and progressive erosion of the catchment.

HYDROLOGIC THRESHOLDS FOR SHALLOW LANDSLIDES IN MOUNTAIN WATERSHED: A SPATIALLY DISTRIBUTED SIMULATION ANALYSIS

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The spatially distributed approach provides an insight of hydrologic factors of shallow landslides triggered by extreme rainfall events. For the purpose, we developed a fine resolution grid model of basin surface including a detailed soil characterization. The soil model includes the infinite slope stability equation, hortonian infiltration, weight of vegetation cover and root strength. The model provides the safety factor for each element at any time step as the representative index for slope instability as produced by a given rainfall hyetograph. We used this model to investigate slope dynamics for a small mountainous catchment in the Versilia watershed, NW Tuscany, Italy. Fine resolution soil and storm data allow to investigate the effects of temporal and spatial scales in the mathematical representation of complex physics. It is seen that one can reproduce the observed slope dynamics only if a high spatial distribution is adopted. Accordingly, the spatial distribution of estimated safety factor is capable of reproducing that of the mass movements occurred during the flood event. Further simulations using syntetic hyetographs can help evaluating hydrologic thresholds for shallow landslides in the catchment. Preliminary analysis of simulations indicates that the extention and spatial distribution of critical values of the slope instability index depend on the return period of total rainfall depth in a storm. This could perspectively allow to evaluate hydrologic thresholds for shallow landslides based on climate, soil and topography characterization.

RETURN PERIOD ASSOCIATED TO RAINFALL THRESHOLD FOR LANDSLIDE TRIGGERING

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The analysis of landslides triggered by rainfalls is based on the hypothesis that the behaviour of the hillslope can be assumed as stationary In such case, it is possible to define some rainfall threshold for the triggering of the slide movement Usually the threshold is defined on a filtered process, called mobility function, defined as a convolution between the rainfall intensity in the past and a filter function, characteristic of the landslide studied In the paper an analysis of different landslides characterised by single or multiple movements in the Southern Italy is carried out Particularly the difference among the various filter functions is studied, higlighting the different behaviour of landslides characterised by a rapid or a slow reaction to the rainfall input Moreover the attention is focused on the variation of the return period associated at the rainfall thresholds These latter are evaluated, for different durations, by assessing the minimum constant rainfall able to produce the attainment of the mobility function threshold In such way, the dependence of the critical rainfalls on the duration is investigated The return periods of these critical rainfalls are evaluated by a statistical analysis of the extreme rainfalls The statistical distributions employed for the assessment of the return periods, are different according to the duration considered. For short duration (some days) distributions highly skewed are assumed, while for the rainfall accumulated on long period (of some week) distributions less skewed are preferred

LANDSLIDES TRIGGERED BY THE HEAVY RAINFALL ON JULY 1997 IN THE CZECH REPUBLIC

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On 4 - 9 July 1997 a heavy rainfall event heavily affected the eastern part of the Czech Republic. During 5 days the precipitation exceeded about 400 - 500% the long-term normal, with maximum 617 mm/5 days. Large areas were affected by slope instability. A several hundreds landslides were registered during this event. The roads, buildings and main railways were damaged in many places. Landslides were concentrated particularly in the region of the Carphatian Flysh, especially in the territory where a claystone formations predominate. Most of landslides had a short and dangerous evolution. In many cases the old landslide bodies were reactivated. The earthflows and stream-like landslides predominated. In the contribution the first results of landslide inventory and analyses are demonstrated.

The Effect of Rainfall on Landslide Triggering in Northern Israel: an Example of Slope Instability in an Active Seismic Environment.

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Abundant seasonal rainfall combined with steep unstable slopes and a high level of current seismic activity contribute to increase the vulnerability of populations and of infrastructures in northern Israel as well as in neighboring areas. Understanding the effects of rainfall on the present non-seismic activity of unstable slopes is the key to further predictions of their potential co-seismic behavior. A multi-parameter monitoring project was undertaken over a period of 24 months on a dip-slope landslide. The present aseismic slip rate and deformation were quantified using five parameters: rainfall, water table level fluctuation, radon emission, surface and subsurface displacement. Results show that intense and irregular rainfall followed by a rapid recharge of the water table have little influence on the activity of the landslide whose slip surface is permanently located below the water table. This explains why past seismic-triggering of landslides also occurred during the dry season.

HSB1 Water resources research

02 Influence of environmental and antropogenic change on flood processes (joint with NH)

Convener: Blöschl, G.
Co-Convener: Burlando, P.

THE ROLE OF DESERT FLOODS IN SPREADING POLLUTION ALONG AN ALLUVIAL AQUIFER: THE NORTHERN NEGEV DESERT, ISRAEL

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Floods along arid ephemeral streams are considered as the major source of groundwater recharge into the shallow alluvial aquifer. The latter, however, is served as an intermediate sub-surface storage for deep percolation and recharge into deep regional aquifers. Contaminants accumulated in upper basin reaches, may be transferred by floods, spread along the riverbed, and may percolate into the shallow aquifer. The level of the contamination is controlled by the rate of streambed infiltration and by the hydraulic properties of the alluvial sediments. As the level of pollution is diluted downstream, the longitudinal flux along the alluvial aquifer and mixing with local water control the spatial distribution of the groundwater pollution. Antropogenic pollutants and industrial contaminants have accumulated in the upper Beer Sheva wash in the Northern Negev desert, Israel. Geomorphic structures coupled with multi-variable cluster analyses performed on dissolved chemicals and environmental isotopes in the shallow groundwater were used to discretize the alluvial aquifer into hydrological compartments. A multi-cells mixing cell model was applied to identify and to quantify sources of recharge, rates of streambed infiltration and longitudinal fluxes along the shallow alluvial aquifer. Results elaborate on the role of floods in relation to the geomorphic structure in transmitting pollution along graveled-bed aquifers.

INFLUENCE OF THE ENVIRONMENTAL AND ANTROPOGENIC CHANGE ON FLOOD PROCESSES OF THE INFERIOR SECTOR OF THE DANUBIAN RIVER

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In analysing the influence of the antropogenic change on the flood processes of the inferior sector of the Danubian River, the general schema of the impact studies was used: the generating process of changing was hydraulic structures of the inferior sector of the Danube, the direct receptor environment - the of the Danube, the transfer characteristics of the flow of water and sediments and of the river bed, the indirect changed environment - the delta and the sea coast. The hidraulic accounted structures are: the Hydroenergetique system Portile de Fier, the The consequences on the flow components (water and sediments) was revealed as well as the modification of the morphological structures of the river bed.

HYDROLOGY AND FOREST : A MODELLING APPROACH ON THE MONT LOZERE (FRANCE)

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In the framework of the European project FOREX, the impact of forest and silvicultural practices upon extreme flows of rivers is studied on three small experimental watersheds located on the southern flank of the Mont Lozere (Massif Central, Cévennes, France) and characterised by a mountainous and Mediterranean climatic influence. Each watershed is covered by a specific type of vegetation (grassland, beech and spruce). A clearfelling has occurred on the spruce watershed followed by a slow reforestation. A lumped hydrological model able to simulate the soil moisture has been calibrated on the three watersheds by comparing simulated runoff with observed data. In order to validate the simulated soil moisture evolution, an automatic measurement site has been settled on the two forested basins. Difference between parameters values is studied in term of vegetation cover influence on hydrological processes. We analyse the parameters values evolution in parallel with vegetation cover change on the spruce watershed. The stability of the model calibrated parameters is controlled on the two other watersheds where the vegetation cover is stable during all the observation period. This modelling approach appears useful to quantify the influence of forest on water storage in soils and on losses by interception and evapotranspiration,. On the other hand, the forest protection against floods, especially against the well known and spectacular Cevennol floods, is not clearly demonstrated, in agreement with previous studies.

FORESTS AND FARMLAND ABANDONED CATCHMENTS: A COMPARISON OF FLOOD PROCESSES

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Flood processes are closely linked not only to the characteristics of rainfall events but also to the main features of the catchments (slopes, plant cover, permeability of soils). To integrate all these factors, the Pyrenean Institute of Ecology has monitored two catchments in the Borau (Loma de Arnás catchment) and Aísa (San Salvador) Valleys, Central Spanish Pyrenees. Information on precipitation, air temperature, soil humidity, sediment transport and discharge has been obtained continuously since 1995. The purpose of this paper is to study the characteristics of the floods in two catchments, one occupied by abandoned fields and another by a dense forest cover. The results show the effects of forest recovering on peak flows and on time lag since the beginning of the precipitation and also allows to establish seasonal comparisons.

RISK OF FLOODING AND PROBABILITY OF EXTREME FLOODS

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Risk is the potential of unwanted consequences from impending events. Risk assessment involves the conversion of consequences to a numerical loss and an often applied measure of risk is the statistically expected loss i.e. the sum of products of the losses and their corresponding probabilities. A common impression of an increase in the risk of flooding thus does not automatically imply an increase in the probability of extreme floods. Factors creating risk of flooding are analysed on the example of the Glomma River (40000km^2) in Norway in this perspective. These factors can be divided into upstream controls in headwaters and main rivers and on site characteristics of a floodplain. The influence of individual changes in land use by deforestation etc on floods in headwaters can be studied by physical approaches like derived distribution functions. However, these approaches at present have limitations when it comes to the upscaling to large basins. Synchronicity in time of floods in headwaters significantly effects the character of the downstream flooding. Empirical scaling relationships of floods with different return periods offer a better tool for analysing this synchronicity and also the effect of regulation in the main river system. The on site characteristics of a floodplain are of importance for both the probability of flooding and the cost of damage by the flooding. These characteristics include the channel properties as expressed by a stage discharge curve, the topography of the floodplain including artificial levees and embankments and the degree of economic exploitation. The contribution of the latter factor is constantly increasing causing an increasing risk of flooding.

A DIGITAL DATA BASE OF CATCHMENT CHARACTERISTICS FOR ASSESSING ANTHROPOGENIC EFFECTS ON FLOOD PROCESSES

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Regional analyses of flood processes are greatly facilitated by a coherent data set of catchment characteristics covering the entire region with sufficient detail. We have used the digital data base of Behr (1989) as a first step. This data base covers all of Austria (totalling an area of about 90000 km^2) and consists of (a) the boundaries of 20000 natural catchments with a total of 10^6 nodes and (b) the stream network with a total of $7 \cdot 10^5$ nodes. Both pieces of information have been digitised at a 1:50000 map scale. As a second step, this data set is being combined with stream gauge locations. This gives the boundaries of about 500 gauged catchments. As a third step, these data are being combined with a digital elevation model of the region and with land-use data derived from Thematic Mapper images. This allows us to derive topographic characteristics (such as mean slope) and land-use characteristics (such as percent forested area) for all catchments in a coherent way. As a fourth step regional flood frequency data are now being examined in the light of these catchment characteristics. This is done (a) by a downward approach by deriving and regionalising statistical relationships between flood frequency characteristics and catchment characteristics, and (b) by an upward approach by derived flood frequency simulations. The latter analysis makes use of additional data such as rainfall and a regime type classification of catchments based on the seasonal variability of stream flow. Both approaches will allow us to examine the role of land-use and/or climatic forcings in the regional distribution of floods and to analyse the potential impact on flood processes of anthropogenic changes in land-use and catchment management. Preliminary results of the analyses will be presented.

Behr, O. (1989) Digitales Modell des Oberflächenentwässerungssystems von Österreich. Technical Report No 11, Institute of Hydraulics, Hydrology and Water Resources Management, Technical University of Vienna, 65pp.

LAND-USE CHANGES INFLUENCING STORM RUNOFF GENERATION AND THE POTENTIAL OF DECENTRALIZED FLOOD RETENTION MEASURES TO COMPENSATE FOR SUCH CHANGES – A SURVEY

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Decentralized flood retention measures are extensive measures reducing and delaying storm runoff generation throughout the whole catchment area. A reduction of storm runoff generation can be achieved by afforestation, cultivation practices preventing overland flow, or structures like hedges or balks subdividing hillslopes, for instance. These measures should be adopted in parts of the catchment with a specifically high runoff production rate. In a wider sense, numerous small measures along the channel network are called decentralized as well.
The aim of decentralized flood retention measures is to compensate for anthropogenic changes within the catchment. But so far, measurements documenting the impact of such measures at different scales are rare. In this contribution, conclusions about their potential for runoff reduction are drawn by reviewing studies focussing on the impact of urbanisation, reallocation of land, deforestation, or river regulation on runoff generation and flood runoff, respectively. This review leads to a qualitative estimation of the extent to which the flood response of a catchment can be influenced by human activities.

ON THE IMPACT OF FLOOD-CONTROL RESERVOIRS ON HYDROLOGIC RISK

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A distributed model of catchment dynamics has been used in order to evaluate the impact of flood-control reservoirs on downstream flow propagation under variable storming conditions. The catchment model calculates local contributions to infiltration excess runoff at each elemental cell by means of a time compression approximation water balance model and routes these contributions throughout a conceptual drainage network extracted from digital elevation model data via a diffusion wave routing model based on the Muskingum-Cunge method with variable parameters. Level pool routing is modeled via a fourth-order Runge-Kutta routine. The reservoir is described in terms of elevation-storage and elevation-discharge curves so that the outflow is calculated dynamically during flood events in response to the inflow hydrograph from the controlled upstream drainage area. The obtained model is applied to the approximately 840-km^2 Sieve catchment (Central Italian Appennines), where the 69×10^6-m^3 multi-purposes Bilancino reservoir controls an upstream drainage area of about 150 km^2. The impact of the Bilancino reservoir on the hydrologic risk for the downstream Sieve catchment is evaluated by comparing hydrograph peaks and times to peak at several sections along the catchment mainstream, as simulated by the model for the natural (without reservoir) and controlled (with reservoir) scenarios.

FLOW ROUTING IN LARGE RIVER BASINS

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Due to recent advances in several areas, it now appears feasible to predict discharges of water and suspended sediment at all locations in a river basin, given sufficiently-accurate topographic data for the basin and a sequence of remotely-sensed or model-derived rain field snapshots. A robust solution to this problem requires the ability to successfully perform the following tasks: (1) fast and reliable extraction of river network flow lines from available digital elevation data (which may not be "hydrologically sound"), (2) a complete, physically-based theory of downstream hydraulic geometry (which can be used in conjunction with existing gauging station data to self-consistently assign values to regions in the basin for which data is not available), (3) a robust and tested method for parameterizing flow resistance in a complex setting, and (4) a vertically-integrated numerical flow model in two space dimensions. Substantial recent progress in each of these areas will be explained, and some of the computational challenges of generating real-time forecasts with short lead times will be discussed.

MODELLING CLIMATE AND MAN-INDUCED EFFECTS FOR FLOOD RISK ASSESSMENTS: OPEN PROBLEMS AND RESEARCH PERSPECTIVES

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In this decade the repeated flood disasters that occurred in urban areas of Europe with high damage and loss of human lives have emphasized climate and man-induced effects on floods as a fundamental research commitment with major implications in both hydrological science and engineering. Current flood risk analysis methods require to be improved to account for these effects, and some of deterministic and stochastic models presently used for prediction of design floods must be revised under this view. New insights and benefits could be obtained from the increase of knowledge on hydrological processes that has been achieved in the past two decades, resulting in the improvement of the physical basis of hydrological models. However, a number of problems and difficulties still remain unsolved, when using physically based models to approach the assessment of flood risk and the design of engineering works under the impact of climate and human activities. Some examples are presented and discussed addressing open scientific issues that might be properly investigated by jointly considering the scientific advances and the engineering requirements of flood related problems.

HYDRA – a Norwegian research programme on floods.

Lars A. Roald (Norwegian Water Resources and Energy Administration)
Arnor Njøs (Centre for Soil and Environmental Research)

Abstract

The HYDRA research programme has been established to examine the hypothesis that the sum of all human impacts in the form of land use, regulation, flood protection etc., may have increased the risk of floods. The main objectives is to extend our knowledge of the connection between natural resources and human impact in the watercourse and throughout the catchment on the one hand, and floods and flood damage on the other. The programme shall propose measures to prevent damaging floods, and to reduce flood damage in a cost effective and environmental optimal manner. The programme was established by the Norwegian Water Resources and Energy Administration in early 1996, and will terminate in 1999. The cost of the programme is NOK 17-18 million with 47 participarting scientists from about 15 Norwegian institutions. The leader of the programme is Professor Arnor Njøs.

The scientific work is performed by a number of project groups: N – "Natural resources and land use", T – "Urban areas", F – "Flood reduction, flood protection and flood management", R – "Risk analysis" and MI – "Environmental consequences of floods and flood prevention measures". The scientific work is supported by the D – "Databases and GIS" group and the Mo – "Modelling group". The N-group is studying the effects on floods of geology, soils, forest coverage and in small catchments and. The T-group is studying the impact of floods on the urban areas within the Glomma basin. The F-group has completed a study on historical floods, and studying the effects on floods of hydropower regulation, constructing flood protection works, and the uncertainty of the forecast. The R-group conducts a study on risks of flood damage on houses and agricultural soils, and is developing methods for flood zone mapping. The Mi-group is studying environmental consequences of various measures to reduce flood damage, and will propose how environmental consequences could be included in the planning of such measures. The Mo-group is developing and testing a general model to study and quantify the total effect of human interferences in the watercourse and drainage basin.

The early phase of the programme has consisted in compiling data suitable to testing the original hypothesis. The paper will present some early results of the analyses, which will be completed by the end of 1998 by the various scientific project groups. The final modelling will be completed in the first part of 1999.

Dynamic model of the non-outletted reservoir (DMNOR) and prognosis its level of change.

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It's known fact that processes happen in the stratums between cores of the Sun and the Earth, which influence the level of the non-outletted reservoir (LNOR).However, for all those catastrophic situations there rise produce in the dynamic of reserved lakes. The heliofactors regulate the LNOR through climate, atmosphere, hydrosphere and lithosphere. The connection are watched with the change the parameters of the Sun. The change of the speed of the Earth's rotation leads to endogenic processes and the deformation processes (DP) in the crust. Dislocation of the rotation of the Earth's axis leads to same situation. In the DMNOR, the DP are regulated with the absolute level of the undeground hydrosphere. Antropogenic factors play a srecific role in DMNOR. It's possible to take into consideration the influence of antropogenic factors, as global warming occurs. Hence it follows that DMNOR consist of an established connections of systems: «the LNOR - Sun's activity», by the temperatures and dynamically parameters of the heliosphere. «The LNOR - DP of the Earth», by the Earth's rotational regime. On the example of the dynamic of the level of the Caspian Sea, connections are established in the different systems. The 22-90 year cycles are observed in the trend changes. DMNOR is made up of global, regional and the technical change in many stratums between the Sun and the Earth. And real rise it fall of the water level needs to be of monitored in stratums between the Sun and the Earth.

DETECTION OF CYCLICAL OSCILLATIONS OF TEMPORAL SERIE. OF WATER FLOU AND CONCENTRATION OF NUTRIENT MATTERS IN WATERS OF THE DNEPR RIVER BASIN

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By means of a method of sliding average , research of temporal series of water flou and concentration of nutrient matters of 23 rivers of the Dnepr river basin was made during the long-term period of 1945-1990.
The analysis of the graphs of values of water flou has proved the presence of cyclical oscillations of average annual water flou wich are seen in sequential alternation of phases of fall and rise, i.e. low and high water phases (terms). During the mentioned period of time it is possible to select 2 full cycles of change of the water flou: 1) 1956-59 - 1969-71; 2) 1971 - 1981.
The cycles with such periods of passing and duration, respectively 12-16 and 11 years respectively, are characteristic of majority of the rivers of the basin. Is detected as of concentration of nutrient matters (NO_2^-, NO_3^-, PO_4^{3-}) cyclical ostillations. It is discovered that phases of magnification and diminution of concentration of substances and somilar phases of water flou are simultaneous. A conclusion about possible cyclical character of the processes of anthropogenic eutrophication of surface water is made.

NH3 Earthquake risk mitigation (joint with SE)

01 Models and methods in seismic hazard assessment

Convener: Tsapanos, T.M.
Co-Convener: Christova, C.V.

VARIATIONS OF NEUTRON FLUX IN THE LOW ATMOSPHERE AND DEFORMATIONS IN THE EARTH CRUST

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Variations of thermal and slow neutron fluxes at the level of the Earth surface in the region of Moscow are observed on the plant, developed in the Institute, since 1993. We found out variations of neutron flux with amplitude up to thousands per cents and duration of dozens of minutes, which correlate with new moons and full moons. Cause of this phenomenon is influence of tide force of Moon and Sun and change of gravitation force gradient sign in this time. Formerly analogous phenomenon was detected by us in the seismoactive regions of Pamir.

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SEISMIC HAZARD ACCESSEMENT: NON PARAMETRIC TESTS TO ISOLATE SEISMOGENIC REGIONS

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Our study concerns the seismicity of Portugal and oceanic adjacent area. We use the I.G.D.L. seismic catalog updated in September of 1997. This catalog includes also the historical records of this region. Our starting hypothesis is that the catalog includes several earthquake populations, related to the different seismotectonic structures. To isolate each population we have to test if there is a statistical relation among several samples picked of the catalog. The testing must be performed in a non parametric basis. The catalog is divided into rectangular cells in order to define samples. Each sample is a sequence of pairs made of magnitude classes and frequency values. We pick two or more samples from the seismic catalog and test the null hypothesis that they belong to the same earthquake population. For each test, the cells must be neighbors of each other. The exhaustive testing along the catalog allows the evaluation of the limits of each seismogenic region: the related cells will join to be part of the same seismogenic region. For each of these coalescent seismogenic regions we plot the usual frequency-magnitude data, in order to evaluate the parameters of the Gutenberg-Richter law. This evaluation follows a robust fitting process.

MODEL OF SEISMIC LOADS DISTRIBUTION FOR THE KALININSKAYA NUCLEAR POWER PLANT SITE

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In order to estimate the seismic hazard level for the site of the Kalininskaya Nuclear Power Plant, which is on operation now, the seismic microzonation was carried out. The instrumental method was applied to construct the model of seismic loadsı distribution for the NPP site and the NPP main structures. The field observations included registration of microseisms and that of ground motions generated by non-explosive (pneumatic) source. 396 vertical component records of ground motions generated by the pneumatic source and 432 records of microseisms were obtained at 84 observation seismometric points both for free field and the main structuresı foundations. The estimation of seismic loads was made for three period ranges: from 0.5 up to 2.13 sec (0.47-2 Hz), from 0.3 up to 0.5 sec (2-3.33 Hz) and from 0.16 up to 0.3 sec (3.33-6.25 Hz). The local seismic sources, which are dealt with stationary technogenous sources of noise mechanical vibrations, were revealed on the basis of data obtained for technogenous changed soils under the condition of intensive industrial seismic noises. The quantitative estimations of seismic loadsı intensity for local sources of seismic noises allowed as a first approximation to exclude their contribution from the observed pattern when compiling the maps of seismic microzonation for the NPP site.

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This work is the fillowing stage of elaboration of the new method of grounds seismic hazard assessment.
Revealing the factors on which the seismic danger of grounds depend (damping velocities of seismic waves, periods of more intensive part of oscillations of earthquakes, hypocentral distances and energy class of earthquakes) and defining the connection between these parameters separately for soft soils and rocks, the change of the degree of seismic danger which the change of these parameters for each ground condition turned out. Comparing quantitative descriptions for rocks and soft soils we obtained the degree of the increment of seismic intensity in compared ground conditions.

EARTHQUAKE HAZARD MAPS AND STRONG EARTHQUAKES: ASSESSMENTS AND REALITY

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Traditionally the level of seismic hazard in some countries is measured in terms of intensity scale, and certain intensity values ("basic intensity") are assigned to every region by Building Codes to be taken as guiding principles in construction of public buildings. Strong earthquakes of M=7, occurred during last 20 years in the USSR and Russia, showed that the assessments of seismic hazard for regions of the events occurrence, must be revised, because the earthquakes were more severe than the Building Code provisions allowed for. We carried out new assessments of "basic intensity" using method of probabilistic seismic hazard estimation developed by the authors. The method is based on Cornell's (1968) procedures, and it incorporates into analyses information on ground motion, seismicity and tectonics, and allows to consider both regional and local features of seismic waves propagation. When employing the method, we used, as far as possible, the data on seismicity that were available before the earthquakes. Therefore, this study may be considered as a test of our approach and technique. The results demonstrate that our assessments of "basic seismicity" confirm the observed data, and they may be used as a reliable basis for Building Code provisions.

NATURAL AND TECHNOGENIC SEISMICITY ASPECTS FOR KUZNETSK BASIN OF ALTAY-SAYAN FOLDEN REGION

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The Kuznetsk basin (Kuzbass) is one of the major structure of the Altay-Sayan folden regions of the southern West Siberia. The great number of mines and enterprises plants are located here. The Kuzbass is a region of low seismicity, but there is a vexed question to assess regional seismic hazard. Powerful explosions are used there for mining purposes. At present seismicity activizing of this territory is observed. Since 1988 there was happen the series of seismic events caused significant macroseismic effects. This events are connected both with tectonic processes and with violation of the dynamic balance in the large mine(s) massif. Principal distinction between natural and tectogenic events are based on foci depth, location near or far from a mine and where or not the current shock rate deviate from background earthquake rate. The problem of the discrimination between earthquakes and chemical explosions is the main one of Kuzbass. We began to prepare the regional catalog of the earthquakes 1963-1995 years where being founding evident explosions and events with explosion-like waveforms are marked.

EXTREME VALUES THEORY FOR MAPPING OF SEISMIC HAZARD IN ALBANIA

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Based on extreme value's theory (first and third Gumbel distributions) the mapping of seismic hazard in space and time was performed for the territory of Albania. Missing events of smaller magnitudes were considered based on normalized seismic activity maps. It was considered that despite of lack of important seismic events in particular regions during the particular periods, normalized seismic activity maps showed that there is a continuous seismic background which has to be taken into consideration during the assessment of seismic hazard for a particular region. The outputs of studies carried out, were presented through the maps of maximum expected earthquakes and total magnitudes(or total energy released during the particular period of observations taken into consideration for computation purposes). Comparison of observed and predicted events showed a good coincidence for some particular regions and the importance of great linear foci , which are characteristic for Albania, in the seismic hazard assessment procedures.

EXPERIMENTAL DETERMINATION OF RESONANCE FREGUENCIES OF LOOSE SEDIMENTARY LAYER

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The ratio of relationships 4H = nV/f (where n = 1, 3, 5, ..., V is a velocity of seismic wave propagation, and f is a resonance frequency of a layer), obtained according to P- and S-waves in one site, provides a curve with the first minimum corresponding to resonance frequency of S-waves, and with the first maximum corresponding to resonance frequency of P-waves. 10 earthquakes with epicentral distances less than 100 and K(9 are recorded in 3 sites located on hard frozen and detrital grounds (T(-1.80C) with an average thickness of 100 m at a dip angle of layer-halfspace boundary of 50, and in 3 sites located on permafrost rocky grounds (T(-30C). A high resolution of spectra on frequency was 0.5-0.75 Hz, and an error did not exceed 0.2. As a result of it, resonance frequencies were assessed. In the first site they were 1.7 - 2.3 Hz for S-waves and 4 - 5 Hz for P-waves, in the second site - 1.4 - 2.0 Hz and 3.5 - 4.5 Hz and in the third one - 1.1 - 1.6 Hz and 2 - 4 Hz for S- and P-waves respectively. An average ratio of resonance frequencies and, therefore, of propagation velocities of P-waves to those of S-waves was 1.6; 1.8 and 1.9. In average for a layer it was 1.75. The ratio of frequency characteristics of P-waves to those of S-waves, obtained for rocky grounds, showed that the components of wave fields, scattered on inhomogeneities, may significantly superimpose on seismic signals, especially at frequencies more than 5 Hz. The minimumsand maximums of the ratio of frequency characteristics is more expressed for earthquakes with epicentral distances less than 100 km.

THE IMPACT OF *b* VALUE UNCERTAINTY ON LOSS ESTIMATION IN THE REINSURANCE INDUSTRY

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In reinsurance industry different probabilistic models are currently used for seismic risk analysis. A credible loss estimation of the insured values depends on the seismic hazard analysis and on the vulnerability functions of the given structures. Besides attenuation and local soil amplification, the occurrence model (often represented by the Gutenberg and Richter relation) is a key element in the input of the analysis. However, earthquake catalogues are usually incomplete or the time of observation is too short and since the data itself have errors, *a* and *b* values can only be estimated with uncertainties. The knowledge of their standard deviation provides a valuable input for earthquake risk analysis, because they allow modeling the probability distribution of expected losses (expressed by average annual loss (AAL)).

Magnitude uncertainties have a direct effect on the estimated *b* values and consequently on the calculated probabilities of occurrence. This effect is best illustrated by magnitude vs. AAL graphs, where the sensitivity of average annual losses due to different standard deviations of *b* is obvious. Thereby, the variations of event occurrence probability due to the uncertainty of *b* are used to quantify a confidence range and the standard deviation of average annual loss.

The estimation of the standard deviation of *b* and the quantification of the sensitivity of AAL are fundamental for an optimal earthquake risk management. Ignoring these uncertainties means that risk management decisions neglect the probabilistic character of the earthquake loss estimations.

UNCERTAINTY IN THE ESTIMATION OF SEISMIC HAZARD AND DESIGN GROUND MOTIONS FOR NUCLEAR POWER PLANTS IN GERMANY

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Earthquake hazard has become an important issue for several nuclear facilities in Germany. The seismic design ground motion parameters for nuclear power plants in Germany have been determined using deterministic approaches in accordance with the existing regulatory requirement. The macroseismic intensity as basic parameter of the design earthquake was related to peak horizontal acceleration to scale the standard USNRC-spectrum (modified in the low frequency range). Design horizontal accelerations range from approximately 0.5 m/s^2 in Northern Germany to 1.5 - 2 m/s^2 for facilities along the Rhine.

Recent strong-motion-recordings indicate, that the standard response spectra used in previous years overestimate the low frequency content but underestimate the high frequency content of strong ground motions in Central Europe and other intraplate / low seismicity regions. Local soil conditions can have a larger influence than previously considered. The input parameters and assumptions for a seismic hazard assessment are connected with large uncertainties. It is important to estimate these uncertainties and their influence on the final result explicitly. Recent advances in the earth sciences require a seismic re-evaluation of nuclear power plants in Germany.

SEISMOTECTONIC CONSTRAINTS ON THE MAXIMUM CREDIBLE MAGNITUDE USING THE GAMMA DISTRIBUTION.

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Recent statistical mechanical and cellular automaton models of earthquakes as self-organised critical phenomenon demonstrate that the most general form of the frequency-magnitude distribution is the gamma distribution, constrained by the mean seismic moment release per event $\langle M \rangle$ and the maximum magnitude m_{max}. This allows a credible maximum magnitude m_{max} to be defined independently by a negligible contribution to the total seismic moment release. Here we apply this method to seismic hazard in the mainland UK and its immediate continental shelf, where the gamma distribution - constrained by a mixture of instrumental, historical and neotectonic data - is used to extrapolate the frequency-magnitude distribution and determine a maximum credible magnitude. m_{max} is found to be in the range 6.3-7.3 for the truncated Gutenberg-Richter law, or 7.0-8.0 m_L for the gamma distribution, compared to a maximum observed in the time period of interest of 6.1 m_L. The upper bounds are conservative estimate based on 100% seismic release of the observed vertical neotectonic deformation, primarily due to glacial rebound, projected onto a single fault. Glacial rebound is predominantly an elastic rather than a seismic process, and the seismicity in an intraplate area such as the UK is likely to remain distributed in space rather than concentrated on a single dominant fault, so the true value of m_{max} is likely to be nearer the lower end of the quoted ranges.

DATA SEISMIC ANALYSIS AND MODEL OF EARTHQUAKE PREDICTION AT THE CHERNOBYL (NPP) LOCAL ZONE

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Discussed the problem of short term forecasting of local seismic events nearby Chernobyl NPP. Authors developed the automatic system of monitoring and provided long term investigations of the Chernobyl NPP (object Shelter) in seismic frequency band. Obtained results allowed build the mathematical model of object reaction on external seismic disturbance and the model of seismic activity prediction. These models used for controlling seismic safety and short term predicting of possible local seismic events. The system further development is supposed to provide quick access ability for the experts to the registered data. To provide maximum access ability to the experts from different countries special Internet node is planned to be organised. This node is to support data base with operative information about local seismic activity on the territory nearby object Shelter. Contribution gives results of practical realisation of this scientific work.

TIME DEPENDENT SEISMICITY IN CHINA

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The regional time and magnitude predictable model has been proved to be the most appropriate one in describing the behavior of strong earthquakes occurrence in all the regions of the continental fracture system (Papazachos *et al.* 1997). It is expressed by the following relations:

$$\log T = 0.19M_{min} + 0.33M_p - 0.39\log m_0 + q$$
$$M_f = 0.73M_{min} - 0.28M_p + 0.40\log m_0 + m$$

where T is the time period between two main shocks; M_p the magnitude of the previous main shock; M_f the magnitude of the following main shock; M_{min} the magnitude of the smallest mainshock; m_0 the moment rate in each region, and q and m are parameters which change from area to area. Based on the seismotectonic and other criteria, the territory of China was divided into 66 regions and the above model has been applied with the aim to estimate the probability of occurrence of the next strong mainshock (M≥7.0) during the next decade as well as the magnitude of the expected event. In order to compare the results obtained by the model with the results derived by the time independent model, statistical tests have been performed. It was found that the "model probability" is almost equivalent to the rate of occurrence of the mainshocks in each area. Furthermore, the success ratio of the model probabilities was found to be more compatible with the real situation than the one estimated by time independent models.

SWEDISH PALEOSEISMICITY AND VARVE DATING

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Today, Fennoscandian is characterized be a low to moderatly low sesmic activity. At the time of deglaciation, the situation was quite different, however. The region was then characterized by both large and frequent earthquakes. The rate of isostatic uplift then amounted to some 10 cm per year (i.e. about 10 times as high as the present sea floor spreading rates). In Sweden, we have the possibility of utilizing the varve chronology for the dating of paleosesmic events. This means that we can achieve an annual resolution despite ages in the order of 10,000 years. This technique has successfully been applied to some regions in Sweden. In the Stockholm region, we have been able to date an extremely large paleo-seismic event to the autumn of varve year 10,430 BP. This event caused liquefactions and varve disturbancies over an area of about 60 x 320 km, which seems to indicate that we are dealing with a magnitude above M 8. We have also been able to identify multiple events re-occurring about every 20 varve (~10,490, 10,469, 10,447, 10,430, ~10,410 BP). A Holocene event occurred along the same fault zone at about 3500 BP. At Iggesund, we have recorded heavy bedrock deformations in association with strong sediment deformations from both ground shaking and tsunami waves, and turbidites over an area of 60 x 210 km at varve 9663 BP.

DETERMINISTIC SEISMIC HAZARD ASSESSMENT OF ROMANIA

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The seismic hazard is described by peak ground motion values (acceleration, velocity or displacement) and design ground acceleration. Synthetic seismograms are computed by normal mode summation for a dense grid of sites covering the whole territory. The computation is made separately for shallow and intermediate-depth sources. Special attention is paid to Vrancea earthquakes which prominently control the distribution of the hazard level. The peak ground motion parameters are compared with the discretized existing maps of macroseismic intensity reported for the large Vrancea earthquakes. Regressions between the maximum observed intensities and synthetic peak ground motion are analyzed. The influence of the focal mechanism in the Vrancea source upon the characteristics of the macroseismic field is investigated. The results of our deterministic approach are finally discussed with respect to other approaches employing the probabilistic method.

REVISED WORLD SEISMICITY CATALOG (1950-1997) FOR STRONG (Ms ≥ 6) SHALLOW (h ≤ 70 KM) EARTHQUAKES

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Using the earthquake catalogs provided by the International Seismological Centre and the National Earthquake Information Center, we analyze the world-wide consistency of teleseismic reporting, completeness of the seismicity record and homogeneity of magnitude determination, for strong ($Ms \geq 6$) shallow ($h \leq 70$ Km) shocks in the period *1950 to 1997*. Under the postulates that the rate of earthquake occurrence for the entire world is constant on a time scale of decades, and that for the last three decades the earthquake catalog for strong shocks is complete and the corresponding seismicity rate is typical of all periods in the century, we find that, due to the use of different formulations and criteria to calculate the parameter "magnitude", the *Ms* of moderate ($6 \leq Ms < 7$) events in the period *1950 to 1963* were systematically overestimated by as much as 0.5 unit, relative to the *Ms* assigned to shocks occurring after *1963*. When this correction is taken into account, the new catalog of events with $Ms(corrected) \geq 6$ in the period *1950 to 1997* becomes largely homogeneous in *Ms*. Under the postulates above, this new catalog is shown to list all and only the strong shocks ($Ms(corrected) \geq 6$; $h \leq 70$ *km*) that occurred in the earth during the period, a notable exception being the time span from *1964 to 1968*. The revised catalog, including the scalar moment for each event, will be released at this meeting.

EARTHQUAKE RECURRENCE FOR NORTH EURASIA: THE THENCHING DATA

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The trenching method in paleoseismic investigation is very popular recently due the reliable and informative results. Some seismic faults of earthquakes of historic and instrumental periods were studied by this technique. For example three trenches were dug across the surface rupture of the Mogod. 1967, Ms=7.8 earthquake on Central Mongolia and two trenches were dug across the visible escarp of problematic paleoruptures of a prehistoric earthquake in Altai. The main results of these researches are: 1. The strong and major earthquake sources are stable structure in geological environment due to the special combination of geological and geophysical condition. 2. Seismic shocks occur in the same source zone repeatedly. 3. An average recurrence period depends on structural and geological condition (in Alpine fold system-several hundred years. in young and ancient platforms-several dozen thousands years.

The model of the seismic process and prognosis of the earthquakes.

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Many dynamic, deformational and rotational features of the Earth, created by the outer and inner forces, have been formed as a result of the interaction of its model parts. In particular, the deformation exceeding the rocks (tensile strength) can happen during 50-600 years, which is the period of earthquakes (EQ) repetition in the varies seismic regions of the Earth. As it is known, EQ are related to solar activity. Its 11-year cycle (s.c.) can be used as unit in Wolf's digits, and the analysis of the EQ distribution during the recent 100 years shows that the period between the EQ of M>8 is 6 s.c., and if M=7.0-7.9 the period is 5 s.c. Inversion of the seismic activity migration occurs during 2 s.c. Analysis of the seismic activity migration at some territory shows that the EQ hypocentre shifts in longitude and for some distances, and such displacement are different depending on the EQ's magnitude. The EQ's magnitude is usually proportional with the square of the spherical surface ,where the outer forces influence the Earth, and its inner reaction against those forces is in action. The radius of that surface (R) can be calculated as $M=Lg(nR^2)$, where R is in km. An example of the prognosis can been seen below. The forecast was done on the 12th of June, 1995, for the second half of 1995. The possible seismic event was expected by the end of 1995 in a place with coordinates $79^0\pm1.5^0$E, $42.5^0\pm0.5^0$N, M=5.5±0.5. The actual EQ occurred on the 31th October, 1995, at $80^0\ 10^1$E , $43^0\ 10^1$N, M=5.0-5.1. At the same time the conclusion had been made that EQ of M≥6 could not be expected in this area in 1995. That prognosis had proved to be correct. There is a new theoretical basis of EQ prediction .

METHODS FOR ATMO-RADIOGEOCHEMICAL MONITORING OF MANIFESTATIONS OF SEISMO- TECTONIC HAZARDS

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Presented are combined methods applied to monitor possible activization of endogenous geoprocesses. Areas with high ecological risk are isolated - specific geodynamic deep-seated zones featuring abnormal geochemical and fluidal regime, and abnormal seismic (active seismic generating faults). The study of neogeodynamic processes is based on the high-informative regional and local airborne survey, particularly, examination of the distribution of methane, radon, uranium, thorium, and potassium found from atmogeochemical and gamma-ray spectrometry made at the altitude of 50-75 m. Airborne equipment includes laser methane gas analyzer with the sensitivity of 0.1 ppm, combined with microprocessor ADSP-2101; radon analyzer which provides measurement of alpha-radiation of atmospheric aerosol sorbed by air filters, airborne gamma-ray spectrometer, etc. Measuring devices are interfaced to navigation units controlled by a computer providing data acquisition, recording and processing.

ESTIMATION OF EARTHQUAKE HAZARD PARAMETERS IN THE SOUTH AMERICA AREA

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Two techniques are applied in order to estimate the earthquake hazard parameters in South America, an area of high seismic activity. These techniques are: 1) the ω values obtained through Gumbel's third asymptotic distribution of extremes, which is considered as the upper bound magnitude and is related to the finite maximum stresses and strains which are currently accumulated and released by the rocks, as earthquake, in a region; and 2) the maximum likelihood approach. This second one provides the regional maximum magnitude, Mmax (which is considered as the maximum possible magnitude in a specific region), the actiivity rate, λ, of the seimic events, the mean return period, R, of earthquakes with certain lower magnitude M≥m and the parameter b of the magnitude-frquency relation. The parameter β is also obtained, which is interrelated to b, with b=βloge. Six depth-ranges subdivisions are defined for the examined area. All the seismic parameters are computed for each individual depth range. In all cases ω values are higher than the regional Mmax estimates. The seismic activity rate is decreasing with depth, while β parameter, which ranges between 1.18 to 2.06, does not show any regularity in its depth distribution. Based on the obtained parameters, we evaluate the seismic hazard of each depth range in South America.

A WORLDWIDE SEISMIC HAZARD ASSESSMENT

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The most reliable data set is used in the present study in order to evaluate the seismic hazard in the whole globe. The data set consisted of a complete and homogeneous global catalog of earthquakes with magnitude Ms≥5.5 and the time covered is from the beginning of the present century. The present study is restricted to shallow (h≤60 km) earthquakes. In order to produce maps of seismic hazard, the whole Earth is divided into a grid point mesh 1°X1° . For each 1° point the parametrs a and b were estimated by least squares method and using a sample of data of earthquakes located inside circles centered at each point. The radius of the circles varied, starts from 30 km and is moving with a step of 10km. Only those values of a and b are accepted which fullfilled 3 predefined condiitions. These are : 1) the number of earthquakes in the circles must be 15 or larger, 2) the number of points in the LogN-M must be 5 or larger and 3) the difference between the maximum and the minimum magnitude of earthquakes in a circle must be 1.5 or larger. Based on these we prepared maps of seismic hazard which is expressed as Mmax observed and concequently as seismic moments and seismic moment rates. These maps effectively produce a brief atlas of seismic hazard.

A HOMOGENEOUS MARKOV MODEL AS A PATTERN FOR EARTHQUAKE RECURRENCE IN SOUTH AMERICA

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The well known statistical model of the Markov-chains is applied in South America in order to search for a pattern of great earthquake recurrence. The model defines a process in which successive state occupancies are governed by the transition probabilities p_{ij} of the Markov process, and are presented as a transition matrix of NxN dimensions. The process $\{X(t), t\geq 0\}$describes the visits to the states and is said to be a Markov process. The magnitudes of earthquakes are firstly defined as states and the obtained results indicate an evidence for a homogeneous behavior of the model, which was verified by the application of the x^2-test. The six predefined zones in which the area of South America is divided are then considered as states. Thus the visits from zone to zone, which is from state to state, carry with them the number of the zone in which they occurred. If these visits are considered to be earthquake occurrences we can inspect their migration between the zones (states) and estimate their genesis in a statistical way, through the transition probability. Attention is given in the zones where the large earthquakes with M≥8.0, in 1906, 1922, 1942 and 1960 occurred. A pattern is revealed which suggests a south towards north migration of large earthquakes. The migration (visit) from zone to zone (from state to state) is given through the estimated transition probabilities.

FROM QUANTITATIVE SEISMIC ZONING TO THE DEFINITION OF CORRELATION RELATIONS BETWEEN GROUND MOTION PARAMETERS AND MACROSEISMIC INTENSITIES

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A deterministic procedure for seismic hazard assessment has been developed at the University of Trieste, Dept. of Earth Sciences, in the framework of the activities of the Gruppo Nazionale per la Difesa dai Terremoti. Using the available information about regional structural models, past seismicity, and the seismotectonic regime of the studied area we generate by the modal summation technique a set of synthetic seismograms covering the territory on a 0.2° x 0.2° grid. The procedure has been recently applied in the Circumpannonian and Dinaric region, and in Algeria. Peak values of ground motion (displacement and velocities) and Design Ground Acceleration based on design spectra extracted from the synthetic signals, can be compared with observed macroseismic intensities wherever reliable intensity maps are available. This is the case of Italy: the correlation relations that we have obtained are in a good agreement with empirical relationships given by other authors and compare quite well with the few observations available in the Italian territory.

B-VALUES FOR ESTIMATING RECURRENCE TIMES: AVERAGE OR ASPERITY VALUES?

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The b-value varies strongly on scales of a few kilometers in most seismogenic vol-umes we have mapped so far by the gridding technique. This is not unexpected be-cause the crust is heterogeneous in material properties and in stress level. One should expect the mean magnitude, or mean rupture length, to vary from volume to volume. These variations are reflected by the change of b-value, which is inversely propor-tional to mean magnitude. Along segments of the San Andreas and the Calaveras faults, we have found that anomalously low b-values of 0.5 correlate with asperities and anomalously high b-values of 1.3 with creeping segments of the fault. Therefore, we hypothesize that seismogenic volumes with anomalously high b-values may not be able to generate major earthquakes; they may only participate relatively passively in major ruptures of neighboring asperities characterized by low b-values. Along the San Andreas fault, we find that the recurrence time is overestimated by three orders of magnitude if it is based on the frequency-magnitude relation (FMD) of the creeping portion, by a factor of four, if it is estimated from the average FMD, and it is estimated correctly from the FMD within the asperity only. We propose that the portions of a fault outside the asperities do not contain information on when rupture may occur, be-cause this is controlled by the asperity exclusively. If our ideas are correct, then recur-rence time calculations based on FMDs should be revised to include asperities only.

VRANCEA REGION- ROMANIA

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The aim of this paper is to present an integrated data system based on satellite remote sensing , geotectonic, "in-situ" monitoring data for seismic risk analysis which estimates the geographic distribution, frequency, and intensity of seismic activity, without attempting to predict specific events.Remote sensing and field studies of active faults can provide a geologic history that overcomes many of the shortcomings of instrumental and historic records. The majority of strong Romanian earthquakes has the origin in Vrancea region, a distinctive active zone of the Alpine orogenic belt placed at the Eastern Carpathians Arc Bend with extensive macroseismic area.GIS/LIS technologies are very useful for a more powerful analysis and decision support tools.

NH3 Earthquake risk mitigation (joint with SE)

02 Seismic hazard evaluation in high seismicity areas by observing precursory phenomena

Convener: Contadakis, M.E.
Co-Convener: Zschau, J.

Sponsorship: Department of Surveying and Geodesy, University of Thessaloniki, GeoForschungsZentrum Potsdam

A NEW APPROACH TO USING THE DATA OF ELECTROMAGNETIC MONITORING OF EARTHQUAKES AT THE TERRITORY OF CHINA

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Seismologists in different seismically active regions of the Earth use, as a rule, the whole set of geophysical methods taking into account the complex character of seismicity processes. It is well known that anomalous changes of different geophysical fields taking place before many strong earthquakes can apparently be considered as precursors of earthquakes. However, in a large set of such precursors there are always contradictory data about the possibility of an earthquake and its parameters. One significant limitation of available prediction algorithms based on studying the development of anomalies of various nature is basically the statistical character of these algorithms. They practically do not take into account the quantitative characteristics of the physical process of earthquake preparation itself. An attempt is made to use the data of monitoring of electromagnetic precursors of earthquakes made available to us by Chinese specialists for reconstructing the time dynamics of some characteristics of the medium in the regions under observation. The analysis of real data has shown that effective parameters of cracking can be reconstructed within the framework of the Archies law with some certainty. In any case, the obtained estimates of the effective parameters associated with the cracking of the medium correlate well with the time of earthquakes.
(The research was supported by RFBR under grant 96-05-66058.)

AN "BOUNDARY DILATANCY LAYERS" AND THEIR INFLUENCE ON THE RELATION BETWEEN GEOPHYSICAL ANOMALIES-PRECURSORS OF DIFFERENT NATURE

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The space-time variations of anomalies of geophysical fields (stress and strain fields, the gravitational field; distribution of the electrical resistance, the ground water level, etc.) in formation of sources of future earthquakes can be recorded using dense geophysical multidisciplinary observation networks. These anomalies appear at distances of up to 200-300 km. Their behaviour is very unstable. There arise some questions associated with elucidation of the formation mechanisms of these anomalies. Some of these questions are discussed within the framework of the hypothesis for dilatancy of the near-surface layer of the Earth's crust. It has been established by mathematical simulation. The formation of "conjugate" anomalies of geophysical fields in zones of "surface dilatancy" and the corresponding direct and inverse multidisciplinary problems of mathematical simulation of the anomalies are considered.

THE EARTH'S CRUST DEFORMATIONS MONITORING ON KAMCHATKA.

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The Kamchatka Peninsula is located at the junction of the Aleutian and the Kurile-Kamchatka island arcs. This region is characterized
by high volcanic and seismic activity. Geodetic monitoring of Petropavlovsk-Kamchatsky and it's vicinity by laser distance measurement, strainmeter and tiltmeter had been made since 1978 year. Observations are carried out by one-wave and two-wave electronic distance measurements, borehole strainmeter and tiltmeter. The main results obtained from 1978 are as follows: - elastic anisotropic deformations about 3 ppm were observed; - measured deformations were revealed to be interrelated with both earthquakes and volcano eruptions; - trends of line lengths with velocity of about 0.03-0.2 ppm/year were detected; - the Avachinsky volcano eruption of January 13, 1991 was accompanied by 3 ppm deformations; - deformation wave from Hailino earthquake (M=7.0, March 8, 1991) was registered at a distance of 1000 km from epicenter. Its velocity and amplitude were 40 km/h and 1 ppm, correspondingly; - coseismic deformations 0.8 ppm and 100 mkr from the Shikotan earthquake (October 5, 1994 M=8.0) were obtained; - the reactions of strain and tilt from earthquakes of Sanriku (29.12.94),Kobe (17.01.95),Sakhalin (28.05.95) were noticed. - precursor variation of strain before Neftegorsk earthquake appeared several days before and had an amplitude of about 3 ppm. The observations by GPS stations were started in 1995. The continuously observations began in summer 1996. There are 8 GPS stations on Kamchatka now for studing of Earth's Crust Deformations as precursory phenomena before high seismicity. Only one strong earthquake (05.12.97, M=7.7) not far from Kronotski penisula was from summer 1996. Any data of GPS stations as a reaction from this earthquake will be represented.

CURRENT SEISMIC HAZARD , ASSESSMENT BASED ON MULTIPARAMETER MONITORING OF LITHOSPHERE

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Long-standing investigations of pre-, co-, post- and inter- seismic phenomena on the territory of Armenia, based on the multiparameter monitoring of lithosphere shows the following: 1) anomalous geophysical, geological, biophysical phenomena accompanying the preparation and realization of seismic events in general are not related to the earthquakes, they like the earthquakes themselves are related to the Earth's crust deformation under the influence of regional forces of the elastic stresses. 2) The stronger is the Earth's crust deformation, the greater is the value of the anomalies of geophysical geological, biophysical accompanying the earthquake preparation and realization processes. 3) In connection with the Earth's crust heterogenity, its maximum deformation zones in general case, may not coincide with the rupture zones, i.e. with the earthquake source. 4) The anomalies of geophysical, geological, biophysical phenomena, accompanying the seismic event preparation and realization due to the heterogeneity of the Earth's crust, may be observed at any distance from the rupture of zone (i.e. from the earhquake source) within the entire regional field of deformations; Therwith the anomalies of various phenomena in may be more intensive in the zone which is far from the source than in the one which is near to it. In contries like Armenia today it is more realistic and necessary to focus the national effects on stage-by-stage current sesmic hazard assessment.

STUDY OF SEISMICITY IN GREECE AND THE ADJACENT AREAS BY THE SEISMOLAP METHOD

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The paper deals with space-time distribution of seismicity in Greece and the adjacent areas. The applied SEISMOLAP technique (Zschau) gives new measures of seismicity (SEISMOLAP1) and quiescence (SEISMOLAP 2). The advantage of SEISMOLAP in search for precursory information is that it considers both frequency of earthquakes and their distribution in time and space relatively to a point of investigation. A newly developed reference system which allows statistically significant clustering and quiescence to be recognized is applied. Several fault zones in the considered region are investigated by using various versions of SEISMOLAP.

RESONANT DISTURBANCES IN A HOMOGENEOUS ELASTIC WAVEGUIDE AND EARTHQUAKE PREDICTION

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We show that every homogeneous elastic waveguide is neutrally stable and possesses a countable set of temporally resonant frequencies $\{\omega_n \in \mathbb{R}, n \in \mathbb{N}\}$. For each ω_n in this set, the response of the waveguide to a spatially localised two-dimensional (2-D) oscillatory forcing, with the time dependence $e^{-i\omega_n t}$, grows in time at least as $\sqrt{t}$, for $t \to \infty$. The growth $\sqrt{t}$ occurs in the case of a low-order resonance. Also, for a wide set of physically relevant waveguides, there exist resonant frequencies $\tilde{\omega}_m \in \mathbb{R}$, for which high-order 2-D resonances with the growth $t^{3/4}$ occur. Same $\tilde{\omega}_m$ are resonant frequencies for axisymmetric disturbances, with the growth $\sqrt{t}$. The analysis is based on solving the linear initial-value problem for localised disturbances in the waveguide by means of a combined Laplace-Fourier or Laplace-Hankel transform. The asymptotic evaluation of the solution, when $t \to \infty$, represented as an inverse transform integral, is carried out by analysing the spectrum of the waveguide $\{(k,\omega) \mid D(k,\omega) = 0\}$, for $(k,\omega) \in \mathbb{C}^2$. Here k is a wavenumber and $D(k,\omega)$ is the dispersion relation function. Low-order resonances occur for a frequency $\omega_0 \in \mathbb{R}$ for which the equation $D(k,\omega_0) = 0$ has a double root $k_0 \in \mathbb{R}$ in k. In the high-order case treated the root is quadruple. Algebraically growing disturbances can play a role of a triggering mechanism for certain earthquakes. So computing and observing resonant frequencies can lead to a prediction of such earthquakes.

RESEARCH FOR GEOHYDROLOGICAL SEISMIC PRECURSORY PHENOMENA IN GREECE

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Although reliable reports on pre-, co- and post-seismic variation on hydrologic characteristics of a seismic active area were known from the antiquity in Greece, it was only the last two decades that systematic research focused its interest to this potential method on estimating the seismic hazard. These investigations are briefly reviewed and the results are been discussed together with the results of the recent research on underground water level and temperature, which has been undertaken by the Department of the Geodetic Astronomy in the area of Pieria in Macedonia, Greece(22°.6E,40°.2).
From this discussion it turns out that underground water level and temperature variations were clearly observed as precursory phenomena connected with major earthquakes as well as as increased noise connected to the local microseismic activity with a probability 75%. In view of these results we conclude that, among the various methods of indirect monitoring of the tectonic activity in an area, which in addition is of very low cost, is that of the following up of the underground water level and temperature changes in the area of interest. This method is based on the fact that tectonic activity result to tectonic stresses producing alterations to the local water table which in its turn is observed as variation to the underground water level and temperature.

DETECTING PRECURSORY SEISMIC QUIESCENCE IN GREECE USING THE SEISMOLAP METHOD

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SEISMOLAP was introduced by Zchau (1995) in order to quantify seismic clustering and quiescence at one location with one variable. The application of SEISMOLAP to the Greek earthquake catalog of the Institute of Geodynamics of the National Observatory of Athens successfully identified precursory seismicity quiescence prior to five catastrophic earthquakes that occured in different areas of Greece in the last twenty years (Chouliaras et al., 1997). In this study, for a better evaluation of the method, we will present a more thorough investigation by testing it with a larger number of seismic events in order to perform statistical analysis on the results.

OBSERVATIONAL EVIDENCES OF GEOELECTRICAL AND SEISMOACOUSTIC SIGNALS POSSIBLE RELATED TO SEISMIC ACTIVITY ON SOUTHERN APENNINE CHAIN (ITALY).

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The first experimental results regarding a combined monitoring of geoelectric and seismoacoustic signals in a seismic area of Southern Italy are analyzed. A remote station was installed north of the town of Potenza, close to an active fault system, where many destructive earthquakes occurred in past and recent times. The goal is to verify the existence of correlations between geoelectric and seismoacoustic signals and the local seismicity. Preliminary filtering procedures for the removal of meteo-climatic effects and noise fluctuations of anthropic origin were applied. Then, objective methods were used to discriminate anomalous patterns from background noise in electric and seismoacoustic time series. Finally, a deep analysis of the possible correlations between extreme events and incoming earthquakes has been carried out. The results so far obtained encourage the prosecution of the research to improve the knowledge on the local geodynamic processes that give rise to precursory phenomena of electric and/or acoustic nature.

PRECURSORY SWARMS, QUARMS, AND MAINSHOCK HAZARD

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Systematic studies of the predictive relations between swarms and mainshocks, based on the New Zealand and Japan catalogues, have indicated that the state of uniformity of the medium is a factor in seismogenesis, and that the occurrence of swarms depends on high fluid pressure. An implication of these developments is that, in regions of lower fluid pressure, the swarm is replaced by the quarm (i.e. quasi-swarm), which is more protracted in time, but is otherwise similar, and displays the same predictive relations. The performance of these precursors is being tested by the methodology of hazard refinement and synoptic forecasting.

RTL PROGNOSTIC PARAMETER: APPLICATION TO THE STUDY OF SEISMICITY OF ITALY

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A prognostic parameter of strong earthquakes RTL have been proposed some times ago (G.Sobolev, Yu.Tyupkin, 1996a) The idea of the proposed approach is based on the supposition that two stages consecutively follow one another in the focus of a future earthquake, i.e., the quiet stage and the foreshock activization of seismicity; in this process, the quiescence almost always occurs during the stage of accumulation of seismic energy in the course of earthquake preparation. The methodical indication for realization of algorithm of calculation of parameter RTL was the supposition that in the immediate vicinity of the epicenter of the future earthquake the mentioned effects are the stronger the nearer is the moment of its occurrence. The tentative retrospective calculations of this parameter by the example of several strong earthquakes (M>7) on Kamchatka, in Caucasus, in Greece produce satisfactory results. In the present report the results of RTL analysis of earthquakes with M>4.5 occurred in the Reggio Emilia area (Northern Italy) and disastrous earthquakes occurred in the Central Italy on September 1997 are discussed.

CRUSTAL MOVEMENTS OBSERVED IN THE FOCAL REGION BEFORE AND AFTER THE 1995 HYOGO-KEN NANBU EARTHQUAKE (M=7.2)

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Continuous observations of crustal strain, tilt and underground water discharge have been carried out at 2 stations in Kobe, Japan, which are located within the focal region of the Hyogo-ken Nanbu earthquake. At the Rokko-Tsurukabuto station, large strain and height changes caused by the earthquake were observed. Short-term changes particularly before the earthquake were not detected, but a slow decrease of strain rates and a relative upheaval continued for a long time prior to the earthquake. After the earthquake, the Otsuki fault crossing the observation tunnel started dislocations of a rate of 0.1-0.2mm/year. At the Rokko-Takao station, large strain changes and increase of discharge were observed about 3 months before the earthquake,. At the time of the earthquake, a large strain step occurred and discharge increased by a factor of about 6. The strain and discharge recovered to the previous levels about 4 months later.

INVESTIGATION OF TENSELY-DEFORMED STATE IN HIGH SEISMICITY AREAS USING VIBROSEISMIC SOURCES

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The paper deals with the results of the Russian-Japanese experiment of 1995 on studying the structure of vibroseismic fields of powerful sources and a connection between these fields and the tensely-deformed state of the geological medium. Vibrational seismograms and spectra of harmonic signal were obtained on a profile up to a distance of 320 km. They contain information about the Moho boundary and the crust structure in the region of the experiment. The experiment has shown that changes in the stressed state of the medium in seismic-prone zones can be studied using variations of the dynamic characteristics of seismic waves, which pass from a powerful vibrational source through the area of earthquake preparation. A concept of the active vibroseismic monitoring system for seismic-prone zones with heavy vibrators and distributed field seismic arrays is presented.

STRAIN AND TILT CHANGES OBSERVED IN THE 800M BOREHOLE NEAR THE NOJIMA FAULT IN AWAJI ISLAND, JAPAN

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After the 1995 Hyogo-ken Nanbu earthquake (M=7.2), 3 boreholes, 500, 800 and 1800 m deep were drilled into the seismic source fault. In the bottom of the 800m borehole, a new multi-component borehole instrument was installed on May, 1996. We observed a secular strain of extension in the NE-SW direction and a secular tilt sinking toward the SW direction. The direction of these strain and tilt is the same as the fault strike. The strain change also showed undulations with periods of 2-3 months, with after-shocks (M¿3) tending to occur in periods of extensional strain. In an experiment of high pressure water injection into a fault gauge section in the 1800m borehole, we observed clear changes of strain and tilt caused by the water injection. The strain indicated compression as the injection commenced and recovered when the injection closed. In addition to these controlled experiments, strain and tilt changes also recorded daily variations reflecting pore pressure change.

THE FORECASTING FEATURE PREDICTIBILITY COEFFICIENT CONSTRUCTION.

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It is evident that the relation between the seismical events (s.e.) and any of its forecasting feature (f.f.) of anyone geophysical field can not be simple because of very complicated processes of s.e. evolution and the influence of many nonseismical factors on the considered geophysical field as well. So the time gap between the f.f. manifesting and the s.e. is of rather wide range, as well as there are part of s.e. without f.f. and part of manifested f.f. without the following s.e.

The author propose to evaluate the prospectivity of f.f. by the help of so called forecasting feature predictibility coefficient k_p. For the sake of time of s.e. prediction the proposed coefficient has the next construction

$$k_p = \max_{\{k(T),k(T/l)\}} \sum_{j=1}^{N} R_j \Big/ (R_{id}\, N) \qquad (1)$$

where N - the complete number of manifested f.f. and s.e.;

$R_j = \left[oz(\delta T_j / T)\cdot k(T/l)+1\right]\cdot\left[L - k(T)\cdot(\delta T_j/T)\right]$; $R_j=0$ if $R_j<0$; $R_{id}=R_j(\delta T_j=0)$; $oz(\delta T_j/T)=0$.or.1 if $\delta T_j/T>1$or elsewhere, corresponding. In abovewritten expressions δT_j - the time error gap between f.f. manifestation and s.e. T - the scale factor; l - scale factor corrector; L - level, depending of the type of prediction (long-, middle-term and so on). k(T), k(T/l) have to be determined according to maximizing condition in (1).

ANALYZING THE GEOCHEMICAL INFORMATION FOR EARTHQUAKE PREDICTION

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This paper discusses the geochemical information for Earthquake prediction. We have a large database of geochemical information. It includes many geochemical elements from many stations during many years. The first is analyzed the homogeneous dates (very important part is that they should had adequate equipments and methods in time). The second part is restoration of missing dates. We use new methodology for restoration missing dates. For analyzing the precursors behavior we divided dates three parts in time : before Earthquake, Earthquake and Foreshok, and after Earthquake. By correlation analysis were finded interesting results for Earthquake prediction.

THE GEOCHEMICAL VARIATIONS CONNECTED WITH THE SPITAK EARTHQUAKE, ARMENIA

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The following geochemical variations in mineral waters of Armenia were revealed before and after the Spitak earthquake.
1. The annual cycles of dissolved helium with a maximum value in summer and a minimum value in winter had disappeared two years before the earthquake.
2. Approximately two years before the earthquake the geochemical precursor, that we called as "geochemical quiescence" was found. To the moment of the main shock the dispersion of macrocomponent mean contents (HCO3, Cl, SO4, Na, Ca) and pH have decreased, while the monthly mean contents remained stable up.
3. Approximately forty days before the earthquake in gas composition the helium precursor variation, that we called as "phase transformation" was settled. Several periods of the spontaneous helium increase together with the decrease of dissolved one and vice versa with the average content of helium remaining almost unchanged were stated.
4. Two days before the main shock the helium daily variations had disappeared.
5. Immediately after the main shock mean contents of a majority of macrocomponents and helium had decreased, while the dispersion became greater.

SEISMIC-QUIESCENCE PRECURSOR OF EARTHQUAKE ACTIVITIES IN ASWAN AND GULF OF AQABA REGIONS AS ESTIMATED BY THE SEISMOLAP METHOD

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On the basis of the seismolap method, which is recently introduced by Prof. J. Zschau from the GeoForschungsZentrum Potsdam, Germany, the earthquake activities along the Kalabsha fault in Aswan and the Gulf of Aqaba regions, in Egypt are investigated in the present study. Aswan earthquake data were recorded and located by the Aswan telemetered seismograph network, which is operated by the National Research Institute of Astronomy and Geophysics. Earthquakes of this sequence of M (1.5, which occurred during the period from December 1981 to the end of 1995, are classified into shallow- (depth ‹ 10 km) and deep- (10 (depth (30 km) earthquakes in order to carry out the present application of the seismolap method on three data sets (i.e., all-, shallow- and deep-seismic sets). The Gulf of Aqaba earthquake catalogue during the period from 1981 to 1995 is obtained from the Geophysical Institute of Israel. The applied method quantifies the seismic quiescence using the space-time variations of microseismicity. Results of the present experiment demonstrate that the Kalabsha fault zone shows seismic quiescence for M (3.4 earthquakes. The pronounced anomaly of Kalabsha sequence extends over a nearly one year duration and is existed in all the three data sets. It is also characterized by a smooth and sharp amplitude with the deep earthquake sequence in contrast to, its amplitude is of gradually-fluctuated pattern with the shallow earthquake sequence. The most interested feature of Kalabsha seismicity is that a group of significant earthquakes not only a single significant event tends to succeed each quiescence anomaly. In contrast, the present application on the Gulf of Aqaba sequence shows a single quiescence anomaly of about one and half year duration of the seismolap value (S3) before the occurrence of August 3, 1993 earthquake (M = 5.8). It is characterized by a very sharp decreasing amplitude and demonstrates a good example for the seismic quiescence precursor. The above mentioned anomalies of Aswan and Gulf of Aqaba seismic activities are obtained by using values of the method(s free parameters as 730 and 800 days, 50 and 100 km of the time and space window, respectively. A threshold earthquake magnitude of 2 is determined with the both sequences.
Key words: Earthquake catalogue, seismic-quiescence and seismolap method.

Anomalous Preseismic Strain and Tilt preceding Earthquake Swarm off Izu Peninsula in Japan.--- Result observed by Multi-component Borehole Instruments

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Earthquake swarm happened off Izu peninsula about 60 km southwest of Tokyo in Japan from March 3rd 1997. The total number of earthquakes reached to more than 10,000. The maximum earthquake was magnitude 5.7 and the activities continued about two weeks. Our Izu borehole observation station is located almost above the earthquake swarm source region and have a muti-component borehole instrument that can record 3 components of strain, two components of tilt, 3 components of acceleration, temperature eqipping with gyro installed in 150m depth borehole. The instrument recorded anomalous variations of both strain and tilt prior to the begining of the earthquake swarm and an earthquake with magnitude 5.0. The precursory tilt started half a day before the begining of the swarm activity. The variation is related to tectonic stress of northeast to southwest tension applied to this region. The coseismic variation reached to 5x10**-5 for both strain and tilt ,and the data indicated strain extension and tilt down. The detailed analysis will be reported in comparison with other observation. We will also demonstrate a comparison with other seismic swarms occuring in this area in different period.

A MODEL OF EARTHQUAKE SEEN BY ELECTROMAGNETIC OBSERVATION—GASEOUS EMISSION FROM THE EARTH AS MAIN SOURCE OF PRE-SEISMIC ELECTROMAGNETIC PRECURSOR AND TRIGGER OF FOLLOWED EARTHQUAKE

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Through observation of anomaly in environmental electromagnetic-wave (EM) radiation at ELF band of 223Hz, we have learned that the precursor of volcanic activity and earthquake might be owed to degassing from the earth crust. (1) Intermittent sharp radiation of vertical magnetic flux is estimated degassing process that uplifts pore to pore from shelf to reservoir rock. (2) Burst-like horizontal flux radiation owes to gaseous leakage from the surface and often ended to volcanic swarm at Cape Shiofuki,Itoh-city,Central Japan. (3) Slow creeping variation of vertical magnetic flux was estimated gaseous intrusion between sedimentary rock and shelf, and followed by small and shallow earthquakes of M2.7-3.7 within one week at Usami, Itoh-city. (4) Dynamical movement of the radiation area along Sagami trough valley of the recent Odawara earthquake was caught by direction finding of received anomalous signal. (5) Sub-second change in intermittent radiation, quick area transferability and radiation from sea surface indicate gas-phase. (6) At the instance touch to the air the reducing gas is quickly oxidized and produces neutralized current for radiation. (7) Pressure exerted by gaseous movement produces conductivity variation and resulting earth current change. (8) The degassing makes rock fracture widen, weaken and covered with clay and might end to trigger fault slipping.

SEISMOGRAVITATIONAL PULSATIONS AS POSSIBLE PRECURSORY PHENOMENON

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Phenomenon of the sharp increasing of the amplitude of the Earth's seismogravitational oscillations (period range 0.5–5 hours) with duration of 5–20 hours was called the Seismogravitational Pulsations (SGP). These phenomena is observed several days before strong earthquakes (magnitude $\geq$ 6.5). The relationship between the SGP and earthquake center process have been revealed. Generally SGP, observed in St.Petersburg (Russia), preceded the earthquakes around Eurasian mainland. The SGP preceded the very destroying earthquake near Sakhalin Island (May, 27, 1995). The azimuth of the SGP full horizontal vector and direction from observation point towards the epicenter of the earthquake are the same.
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THE SURVEY OF ANTROPOGENIC AND GEOPHYSICAL ELECTROMAGNETIC PERTURBATION BY USE THE MICRO SATELLITE INTEGRATED IN THE ISS INFRASTRUCTURE.

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The main goal of the scientific experiment onboard the electromagnetic clean micro-satellite (EMCS) and ISS station is to study the electromagnetic disturbances in the ionosphere due to anthropogenic activities and natural geophysical phenomena, particualy earthquakes and volcanic eruptions. Most of previous experiments have been performed at heights above 800 km. The EMCS satellite provides the unique oppotunity to carry out regular observations at much lower heights, about 400 km, in the F-layer. In order to reduce influences of the EMCS on the ambient environment its power consumption is limited to 25-30 W and the onboard systems of the ISS are partly used for the data acquisition and transmission.

Structure functions in geophysical flows

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Extended self-similarity (ESS) (Benzi et al. 1995) is used to analyse laboratory and field data of grid generated turbulence and surface wave generated turbulence. The experiments use velocity point measurements obteined from sonic velocimeter SONTEK3-D, Hot-Film or 2D-electromagnetic current meters measured in the surf zone.

We obtain good scaling at moderate Reynolds numbers using the relative scaling exponents $\zeta_p = \frac{\zeta_p}{\zeta_3}$ up to 6th order, some experiments show that the exponents are the same and they do not depend on the Reynolsd numbers Re, they are also different from the scaling $p/3$ of Kolmogorov's theory (K41).

We use the Babiano-Dubrulle-Frick model (1997) for nonhomogeneous and nonstationary turbulence, using ESS, to measure the relative scaling exponents even in nonhomogeneous flow. The turbulence is not uniformly distributed in the flow, there are regions with more intense turbulence, more intermittent, and regions with less intermittency, these may be identified by the values of $\tilde{\zeta}_p$.

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COMPARATIVE ANALYSIS OF TECHNIQUES USED FOR EARTHQUAKE ELECTROMAGNETIC PRECURSORS STUDY

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The existence of electromagnetic (EM) precursors of geological hazards is widely accepted now. Obviously, there are many problems connected both with the diversity of such precursors in dependence on the local geological structure and their low level in comparison with the surrounding EM noises and interference. All these factors make the reliable extraction of corresponding precursors rather difficult. Up to now if do not consider some controversial communications these precursors are observed mainly after the event, processing the observation data. The aim of present study is the comparison of different methodologies of ground based EM measurements and data processing for the extraction of earthquake precursors. Many works are known devoted to different types of electromagnetic precursors study and because their relationship to the seismic activity is highly dependent on local crust structure it is difficult to propose the reliability criterion from all these methods. That is why for the moment only following methods are analyzed: tectonomagnetic survey, EM emission study and extremely low frequency (ELF) active sounding. The expected signal - to - noise ratios and convenience of experimental realization are the comparison base. It is shown the advantages of the last method - ELF active sounding - from every point of view and corresponding calculations are presented.

CRUSTAL DEFORMATION STUDY OF JAPAN BY UTILIZING GSI'S DENSE GPS ARRAY.

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Geographical Survey Institute (GSI) of Japan has been constructing its nationwide permanent GPS array since 1994. Its results on crustal velocity field shows that Japan is located on plate boundary region; the north-east Japan belongs to the Okhotsuk plate, and the south-west Japan does to the Eurasian plate. Moreover, the velocity field suggests that Japan consists of several tectonic blocks. Miyazaki et al. (1996) reported an inversion study for a kinematic block-fault model of the Japanese Islands based on a velocity field obtained by 120 GPS sites of the Geographical Survey Institute. After their study, the number of the GSI's GPS stations increased to 610 from April, 1996. Yarai et al. (1997) performed the same inversion study but modified the model of Miyazaki et al. (1996) using dense GPS data from April, 1996 to March, 1997. In this study, we estimate seismic moment and occurence periods of large earthquakes by assuming that magnitudes of future earthquakes will be the average of historical earthquakes. Our results, for example, suggest that the occurence periods on Nankai Trough is 80 - 120 years, and that in the eastern margin of the Japan Sea is about 200 - 400 years.

SIGNALS OF SYNCHRONIZATION AS PROBABLE PRECURSORS OF STRONG EARTHQUAKES.

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It is widely known that increasing of collective behavior of constitutive parts of some system and enlarging of spatial radius of fluctuations of its parameters could be regarded as an important precursor of oncoming catastrophe, abrupt change of system's parameters values. From that point of view detection of signal of synchronization of various geophysical parameters, measured in points of some network, covering a rather big area of Earth crust, is of considerable interest for searching new precursors of geocatastrophes, including strong earthquakes.

A methodics for detection of a signal of synchronization in multidimensional time series data flow is presenting. It is based on estimating of response functions, eigenvalues of spectral matrices and canonical coherences in moving time windows and extracting aggregated signals (such scalar signal, which accumulates in its own variations only those spectral components, which are presented simultaneously in each scalar time series).

Examples of using this technique to processing of real geophysical time series are presented.

CASCADE EARTHQUAKES IN ALBANIA

Abstract

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A complex web of active faults is distributed throughout all the territory of Albania. The intersection of the northwest-trending Adriatic and Ionian longitudinal fault system and northeast-trending shear fault systems, dominates Albanian tectonics and gives rise to recent seismic activity backed mostly by the confrontation between Adria microplate and Albanian orogen.

Sometimes, activation of some active fault produces the earthquake activity in a neighbour one and this process could continue as a cascade through other faults. This may cause the migration of seismic activity from one system of faults to another and sometimes could lead to wrong deduction about the proper fault responsible for an earthquake.

Based on the available data from the records of Albanian Seismological Network, since 1976, some cases of the so-called cascade earthquakes for Albania are evidenced in this approach trying to explain also their mechanism.

PARAMETRIC SEISMOGEOACOUSTIC MONITORING OF SEISMOTECTONIC PROCESSES AND EARTHQUAKE PREDICTION IN THE UKRAINIAN TRANSCARPATHIANS.

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Spatial-temporal monitoring of nonlinear-elastic and parametric tensoeffects in rocks have been used for long for seismoprognostic investigations in the Ukrainian Transcarpathians; it is an efficient indicator of the rock stressed-strained state variations. Combinations of techniques for point investigation held at the network of points and vibrosoundings makes it possible to detect regions of stimulated seismotectonic processes and registrate direst seismogeoacoustic precursors of local earthquakes (creep movements, tensovariational anomalies and "storms"). Complex interpretation of the data obtained, as well as the data based on other geophysical techniques provide monitoring of earthquake preparation, determination of a scenario, interpretation of mechanisms and, thus, determination of seismic danger.

Radon-exhalation dynamics for predicting tectonic earthquakes

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Radon exhalation in deep mines has previously been found to show the following zonal distribution before mine burts: A radon decrease by factor of 3 to 4 in a zone of compression in the vicinity of the burst and a radon increase by a factor of 8 to 10 in zone of extention at larger distances. A burst event usually occur shortly after the maximum radon change. In the present study we have checked whether a unique set of soil-air radon-concentration data recorded on San-Andreas fault in Caifornia (Chi-Yu King) show similar patterns. Our result shows similar zones of compression (radon decrease), extension (radon increase), and no change for 25 tectonic earthquakes of magnitude 4 and 5, which are always located subsequently in a zone compression. The zone of compression has a dimension of about 25 km for an earthquake of magnitude 4, and 50 km for magnitude 5. The zones of extention usually have a dimension of more than 100 km. The radon values usually begin to show significant changes less then 3 to 4 months before the corresponding seismic events, with maximum changes occurring about 1 to 2 weeks before the events. However such a pattern may be disturbed by the occurrence of forshockes, which may cause additional radon changes. The dynamics of radon exhalation, if properly monitored and analyzed, may be useful for predicting earthquakes.

A TIME CLUSTERING OF STRONG EARTHQUAKES IN GREECE DURING OCTOBER-NOVEMBER 1997

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During October-November 1997 an anomalously high seismicity rate was observed in Greece and adjacent regions with seven main shocks of M_s ranging from 5.1 to 6.6. By adopting the random distribution we prove that the high seismicity episode cannot be attributed to the chance. The calculation of the potential stress-drop stored in each region before the respective earthquake occurrence indicates that all the ruptured regions were prestrained near to failure. On the basis of these results we assume that a geophysical mechanism of triggering earthquakes by earthquakes should be responsible for the strong time clustering. Transient stress changes caused by the triggering earthquakes may play a predominant role in the initiation of the triggered earthquake in a prestrained near to failure region.

SUCCESSFUL PREDICTION OF THE LARGE 18 NOVEMBER 1997 IONIAN SEA EARTHQUAKE

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The M_s=6.6 earthquake of 18 November 1997 that ruptured the Ionian Sea to the south of Zakynthos Island concluded the strong earthquake clustering observed in Greece during October-November 1997. A successful prediction was issued before the large shock on the basis of the seismicity synchronization between the Corinthos Gulf (CG) and Ionian Sea (IS) segments. It was observed that during the instrumental era more than 20 shocks of $M_s \geq 5.2$ in CG were systematically followed by corresponding IS shocks of M_s=5.0-6.5 with a time lag up to three months. When the M_s=5.4 shock of 5 November 1997 occurred an earthquake prediction statement was issued which reads as follows: "a strong earthquake of M_s=5.8±0.7 should be anticipated in the Ionian Isl. within the next three months from 5 November 1997 with a probability of about 80%. The area of the next earthquake is defined as 37.2°-38.8° N, 20.0°-21.7° E". A mechanism of earthquake triggering is discussed in terms of transient strain changes propagating from the area of the triggering earthquake to the area of the triggered one.

SEISMIC HAZARD MONITORING WITH CRETE: *CRETE REGIONAL TECTONIC EXPERIMENT*.

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Intense seismicity in this area and complex geodynamic motions with high rates of deformation make Crete -located in the forearc of the Hellenic subduction zone- a suitable physical laboratory for seismic risk evaluation. A base station for the CRETE array has been in operation for several months now and relative positions of sites from previous GPS campaigns have been determined relative to it. A second permanent site is collocated with the tide-gauge at the Naval Base of Souda, near Chania, monitoring local vertical motions and sea-level variations to verify the uplift rates inferred and reported by Lambeck. There is a plethora of competing underlying lithosphere and driving mechanism models to be validated through observations. Inferences from the analysis of earthquake focal mechanisms and assumed spreading vectors at mid-oceanic ridges suffer from the unavoidable assumption of rigid plate tectonics, a rarely valid assumption. High seismicity areas as Crete, exhibit complex local motions beyond the dominant thrusting plate rate. Detailed characterization of such complex deformation requires a dense local network: either a permanent continuously operating one, or one re-occupied at regular intervals. Continuity improves reliability and allows monitoring of the motion without any assumption about its nature. 3-D deformation monitoring has also gained importance since uplift contaminates tide-gauge-determined sea-level variation signals -- of great interest in studying the sea-level change record for eastern Mediterranean.

PHENOMENA OF LEAP-TYPE ALTERATIONS REVEALED BY SLOPE SOUNDING OF IONOSPHER

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Long term investigations of ionosphere by slope sounding revealed the regularities of alteration of the ionosphere condition in seismogenious zones. Since 1992, in NSSP observations are conducting by radio routes Norway - Yerevan, Liberia - Yerevan, Reunion - Yerevan and Japan - Yerevan of the phase radio navigation system "Omega". Phenomena of appearance of discrete power levels in system Earth - ionosphere in the process of earthquakes preparation has been discovered and is under investigation now. Phenomena displays as leaps of a delay function of radiowaves transmitted from great distance. Such behavior of the delay function can be explained by discrete power levels of energy eradiating by Earth crust in the seismogenious zones.

THE NEW CONCEPTION OF EARTHQUAKES PREDICTION

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The last strong unpredicted earthquakes at US, Japan and Italy, in most advanced technologically and equipped countries, have shown that traditional methods of seismic prediction sometimes fail. During the last decade a lot of papers concerning the electromagnetic and plasma precursors registered at the ground level and onboard the artificial satellites were reported but they were not supported by physical explanation, and therefore, were encountered with great skepticism and opposition, especially from the side of traditional seismologists. In the present paper the concise approach is presented, based on physical foundation, supported by experimental results and corresponding estimations, which, it seems, could be followed by success in prediction of earthquakes in the case of its implementation. The proposed mechanism includes: radon and aerosols emanation from the crust, ionization of gases and aerosols by radon, space charge formation and generation of strong electric field ("1000 V/m) over the anticipated earthquake area, mapping of the near ground vertical electric field into horizontal electric field in the ionosphere, Joule heating, acoustic gravity waves generation, plasma irregularities formation. Every step of proposed chain of physical processes is supported by theoretical estimations and they are consistent with existing experimental results. It is proposed construction of the new global system of seismic warning, including as ground based, so satellite measurements. It could be easily implemented into existing seismic monitoring network, but its main advantage in comparison with traditional methods, that it is able to answer on question "when?", what is inaccessible in present.

LOCAL SIGNS OF EARTHQUAKE PREPARING AND ITS AVAILABILITIES.

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It is discussed some valid signs of the earthquake preparing for seismoactive region. These signs are connected with the critical stress state of the earth crust just before the earthquakes. They constitute the subset of observed parameters and they may be considered as short-term earthquake precurcors. It is proposed to use as such parameters: the faint modifications of the seismic signal before earthquakes; variations of the infrared radiation of the rock massif, the variations of electromagnetic fields, etc. The variability of these parameter are depended on the regional characteristics (features of the environment, structure of the earth crust, the oscillator size). Thus this subset may be unique for each region. The second subset consists of parameters which have to be calculated at every point in time (astrometric data, the Earth-Moon system state, etc). They may increase an earthquake possibility.

THE SOFTWARE SYSTEM FOR THE EARTHQUAKE PRECURCOR DETECTION BASED ON THE REGIONAL MONITORING.

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It is discussed the structure of the real-time software system for monitoring, processing and analysis data for the detection short-term earthquake precurcors. The system have to include the data bases with regional data, set of the real time data processing methods for each parameter, the weight estimation algorithms for the parameters of the given region, the algorithms for the learning and the making decision subsystems. The parameters are divided in two subsets. The first one is the parametr set connected with the earth crust critical state (the seismic signal, the infrared radiation of the rock, the variations of electromagnetig fields, etc). All parameters are treated as one multi-dimentional value described the earth crust stress state. The signal-noise ratio is negligible for every parameter. In these cases more efficient may be using the artificial intelligence methods (the pattern recognition, linguistic, fuzzy logic, neuron networks, etc). The second subset consists of parameters (astrometric data ,etc) which may increase an earthquake possibility at this point in time.

ANANLYSIS OF ICELANDIC EARTHQUAKE PRECURSORS IN THE PRENLAB PROJECT

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Premonitory activity before earthquakes has frequently been observed in Iceland, both instrumentally and historically. Such activity, especially seismic, can be devided into 3 main categories. 1) Foreshocks, i.e. small earthquakes observed hours or days before a larger earthquake. 2) Intense sequence of earthquakes, lasting for days or weeks preceding a larger earthquake, where the preceding sequence has a moment comparable with the main earthquake. 3) A large earthquake of magnitude of about 7 precedes somewhat smaller but catastrophic earthquakes in nearby areas within weeks. Besides these types of premonitory changes it has frequently been observed in history that large events, earthquakes and volcanic eruptions, coincide in time over areas of the order of several hundred kilometers. This has been called strain waves. Besides the seismic premonitory changes comparable observations have been made of radon, volumetric strain, and shear wave splitting changes. Tentative models will be demonstrated for explaining the above mentioned observations.

TEMPORAL VARIATIONS OF THE ATMOSPHERIC ELECTRIC FIELD AS AN EARTHQUAKE PRECURSOR

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Many investigators of the atmospheric electricity observed anomalies in the atmospheric field behaviour before and during some strong earthquakes. The observation results were contradictory because of imperfect and variegated instruments. Special sensitive equipment was developed and used for comparatively long measurements of the electric field strength of the atmosphere in seismically active regions of the Pamirs and Tien Shan. All of observations were conducted with identical electric field sensors. The analysis of the results of measurements showed that the quasi-static electric field of atmosphere. as a rule. experiences characteristic variations shortly before earthquakes. In particular. since several (generally 5 - 7) of hours before an earthquake the value of the electric field strength begins to decrease. then the field strength changes its direction to the opposite. The anomaly lasts from 20 minutes to 4 hours. the most likely meanings - from 1 to 1.5 hour. Besides. it was noted that since several days before an earthquake there exist time intervals with comparatively quick variations of electric field with period in the dozens of seconds. The amplitude of these variations and the duration of the intervals of time for which they are seen grow with approach to the earthquake date. The results of investigations allow to consider the specific temporal variations of the atmospheric electric field as a potential earthquake precursor.

'MOVING CHARGED DISLOCATION MODELLING' OF ELECTRICAL EARTHQUAKE PRECURSORS : A PROMISING APPROACH ?

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We present and discuss a model of EEP generation and propagation as a function of the medium and source-receiver separation, based on the concept of *Moving Charged Dislocations (MCD)*. Signals generated by this process are modulated by a source time function featuring a corner frequency and an inverse power, energy distribution law. This allows the generation of a limited class of signals with characteristic bay-like shapes and duration from a few tens of seconds (close ranges/resistive media/fast source functions) to a few hours. We apply this model to analyse a signal which was associated with the 18/11/92, M5.9 Galaxidi event (Greece). We were able to reproduce the observation in shape, using generic parameters of the earthquake source and the MCD model; reproduction in magnitude is possible, but only under untestable as yet considerations. This apparent success suggests that the MCD model may be promising towards establishing a working theory of the EEP source. Moreover, if data from more than one station existed, the procedure could be invertible to source parameters. This concept is discussed in the context of seismic hazard evaluation.

SEISMIC QUIESCENCE IS SIMILAR TO FORE- AND AFTERSHOCKS

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We hypothesize that the seismicity rate is normally constant. Before and after major earthquakes, the seismicity rate in and near the source volume is often disturbed: Fore- and aftershock sequences are the well known expressions of this, but precursory as well as post-quiescences exist. For the post-main shock quiescence the redistribution of stress due to the main event is the obvious cause, as it is for the aftershocks. Although precursory quiescence and foreshocks are clearly defined in many cases, their cause is not obvious. In some cases they may be explained by precursory aseismic creep. Examples of constant seismicity rate are abundant in deep seismic zones. In 70 seismogenic volumes below 60 km depth of 500 earthquakes each in periods of 8 to 30, we found that the standard deviation was close to that expected from a Poisson distribution. Examples of post-quiescence are found on the San Andreas Fault near Parkfield and along the east coast of Japan, where main shocks of M4.7 and M7.5 were followed by complete absence of earthquakes for several years in neighboring volumes that previously produced large numbers of earthquakes. In the same tectonic provinces precursory seismic quiescence of a few years can be clearly defined for some main shocks, the M6 Coyote Lake and Morgan Hills earthquakes along the Calaveras fault, and the M7.1 off-Sanriku earthquake, Japan. Like foreshocks, precursory seismic quiescence is an obvious phenomenon that is however not understood yet.

NH3 Earthquake risk mitigation (joint with SE)

03 Macroseismics: present state of intensity-assessment procedures and future perspectives

Convener: Tertulliani, A.
Co-Convener: Cecic, I.

PROBLEMS OF INTENSITY ASSESSMENT AT LOCALITIES SHAKEN BY DAMAGING EARTHQUAKE SEQUENCES

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The problem of assessing macroseismic intensity at localities affected by several damaging earthquakes during a short time interval is well known. In such cases, usually, after the first strong shaking the buildings vulnerability is lower than before, though it is not easy to assess "how much lower". Therefore, to assess intensity one has to move through the vulnerability table, with little hints. To neglect these aspects lead in the past to unreliable intensity estimates and, from them; to unreliable magnitudes for aftershocks. This paper analyses some cases, with special reference to three major earthquakes (Io = IX, IX and X MCS) which, in 1741, 1747 and 1751 occurred in a comparatively narrow area of the Apenninic region, then belonging to the Papal States, where also the 1997 earthquake took place. They set in motion the production of huge amounts of official documents (surveys, reports and so on) that give detailed descriptions of damage suffered by single buildings and/or by all buildings in many affected localities. These data provide a "damage record" for many localities of different status and size, from provincial towns such as Fabriano, Nocera Umbra and Gualdo Tadino, to small villages such as Belvedere or Campodonico. Problems of intensity assessement from that record are compared with similar problems encountered when assessing intensity for the recent 1997 sequence.

SEISMIC HAZARD ESTIMATES FROM FELT INTENSITIES AT THE SITES SHAKEN FROM THE 1997 CENTRAL ITALY EARTHQAUKE

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In order to fully exploit available macroseismic data concerning earthquakes that in last centuries shook central Italy, seismic hazard analysis has been carried out by using non standard statistical techniques. In particular, methodologies developed for the analysis of ill-defined macroseismic data have allowed the combined use of intensity estimates deduced from documentary sources or computed from epicentral data by taking into account the different level of data reliability. Furthermore, the proposed approach also allows the use of the whole seismic history by also taking into account the time varying completeness of the available seismic catalogue. Since the adopted data set concerns a time interval spanning from 1000 A.C. up to 1980, the comparison of seismic effects observed during the last seismic crisis in Central Italy (september-october 1997) with the ones expected on the basis of seismic hazard estimates supplied by standard procedures and by the one here proposed, could allow a check of the relative reliability.

A DISTRIBUTION-FREE ANALYSIS OF THE MAGNITUDE-INTENSITY RELATIONSHIPS: AN APPLICATION TO THE MEDITERRANEAN REGION

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A procedure for the statistical analysis of the relations between macroseismic intensity and magnitude is presented. In order to overcome the problem due to the heterogeneous nature of the two quantities involved, intensity and magnitude, relationships have been studied by means of a distribution-free statistical approach. The data-set examined is constituted by earthquakes of epicentral intensity >=VI occurred in the Mediterranean region. As known, magnitude-intensity relations depend on a number of local features (e.g. average hypocentral depth, etc.) but, owing to the nature of the adopted data-base (resulting from the integration of many national and regional seismic catalogues) they can also be affected by the use of different macroseismic and magnitude scales. The role of every variable able to influence the magnitude-intensity relations (i.e. intensity scale, source catalogue and earthquakes location) has been evaluated by means of an opportune correlation analysis (e.g. Cramer correlation coefficient).

A New Attenuation Law for the 1755.01.11 Lisbon Earthquake

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The 1755.11.01 Lisbon earthquake was felt strongly on Portugal, Spain and Morocco, specially along the Atlantic coasts. The intensity at the epicenter is estimated in XI (MSK) and its magnitude, inferred from macroseismic data, is 8.3/4 (Guttenberg and Richter, 1949). The tsunami magnitude, Mt=Mw, was estimated by Abe (1989) based on the tsunami run up data observed along the Iberian coast. Macroseismic Intensity maps were published for Portugal, Spain and Morocco separately and the corresponding attenuation laws were fitted. Most of these laws are based on the assumption that this event was generated in the same oceanic region and by a similar rupture mechanism that the recent instrumental event that occurred on 19169.02.28. The recent hydrodynamic simulations on the 1755.11.01 Lisbon tsunami showed that the location of the source area and the rupture mechanism are different from the 1969.02.28 event that was located at the Horseshoe Abyssal Plain (North Atlantic), Baptista et al., 1998). In view of these results a new compilation of macroseismic Intensity data was made with data from Portugal, Spain and Morocco and a careful revision of the existent attenuation laws was made. The new attenuation law was fitted using 820 data points and Levenberg Marquardt algorithm.

THE ZAGREB 1502 EARTHQUAKE - DOUBTFUL OR EVEN FAKE?

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In the BEECD working file, and before that in Balkan catalogue, the earthquake on 26 March 1502 at 13 h has intensity IX MSK. The similar entry can be found in the Croatian earthquake catalogue. Its historical part relies a great deal on Kispatic (1891). The oldest source given by Kispatic for this earthquake was a chronicle written by Joannis Tomasich in 1561: "Anno Domini 152. die 26 Martii hora 2 post meridiem", and the tower of St. Marcus church in Zagreb was destroyed to the fundaments. The year of the event is written in a way that could lead to different interpretations. The Valvasor's famous chronicle also quotes Tomasich as a source for this earthquake, but giving the date 6 March 1502. The damage on the tower is not mentioned in the books of the St. Marcus church (Kispatic, 1879). Also, the annual overview of the Bishop's expenses for the time period 1501-1505 does not show any increase in the sum for the regular maintenance of Zagreb chatedral, which is about 500 m away from St. Marcus. Moreover, king Vladislav II (Wladislaus) allowed the city of Zagreb to use taxes to repair the bad condition of the houses after the recent earthquake; the document was dated in 1511 (Tkalcic, 1896). Although there is still a lot of work for the historians to be done to find more proofs of our hypothesis, we believe that the described effects speak about the event on 26 March 1511 at 14:30, which occured in border region between Slovenia and Italy.

THE USE OF THE EMS-1992 SCALE IN THE FIELD WORK: EXAMPLES FROM THE CENTRAL ITALY, SEPTEMBER - OCTOBER 1997

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In September and October 1997 the regions of Umbria and Marche in Central Italy were hit by a sequence of strong and damaging earthquakes, with epicentres in the vicinity of towns Nocera Umbra, Colfiorito and Sellano. Few days after the first earthquake an ad-hoc expert team was formed of the seismologists, geologists, historians, architects and geographers who made quick survey of the most devastated area. The macroseismic data were collected in a great extent, in order to be able to use EMS 1992 scale while estimating the intensities. A preliminary field form was constructed and used as a common base for the collecting of data. Several problems were met during the field work and intensity estimation process, due to a lack of experience with EMS on the one side and the huge damaged area that was getting bigger every day on the other. Main problems were how to establish building typology and how to separate damage effects of different shocks. The field experience led us to believe that some improvement in the scale is needed in order to give more indication about building classification and building behavior and resistance after damage. During the field work we discussed a possibility of "inserting" a degree between VI and VII, as in many localities the observed damage was more than VI and less than VII.

DISTRIBUTION OF EFFECTS IN THE URBAN AREA OF ROME, FOR THE OCTOBER 14, 1997 (CENTRAL ITALY) EVENT

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During the last years many improvement have been done by historical seismologists outlining more and more the response to the seismic shaking of the downtown of Rome, at the occurrence of large earthquakes. Till now, only historical data evaluation were available to check the seismic vulnerability of Rome. The possibility to verify our knowledge on the basis of recent earthquake was the occurrence of the October 14, 1997 event, located in the Central Apennines region (M_W=5.7), which has been largely felt in the city of Rome (far about 115 km). A prompt macroseismic survey in the Roman urban area was performed, to obtain the picture of shaking in the whole city. For this earthquake, we were able to collect macroseismic information related to several hundreds topographic points. It is the first time that such a large amount of data is available for Rome. The analysis of the data points out a preferential distribution of larger effects within Holocene alluvial sediments, but it also allows us to individuate some areas where local amplification phenomena occurred. Such areas are characterised by recent terrain hosting more levels of water-tables.

MACROSEISMIC SURVEY OF THE CENTRAL APENNINES EARTHQUAKES OF SEPTEMBER-OCTOBER 1997

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After the two first major shocks of September 26, 1997, in the Umbria-Marche area, the National Group for Defence against Earthquakes of Italy's National Council of Research (GNDT/CNR), the National Seismic Survey (SSN) and the National Institute of Geophysics (ING) started a joint macroseismic survey. At first, a preliminary evaluation of the maximum effects and a rough delimitation of the damaged area were effected using data gathered by field investigation and also - due to the extension of the damaged/felt areas - through press and technicians' reports and telephone interviews. From October 3, a more detailed field survey started in the most heavily damaged localities, with the aims of discriminating (whenever possible) the effects produced by each of the main shocks, to test the European Macroseismic Scale EMS-92, and also to record the worsening of damage scenarios, progressively caused by the strongest aftershocks. New stages of the survey were carried out after new damaging aftershocks, on October 8 and from 16 to 19 October, particularly in the areas of Sellano, Preci, Alta Valnerina and Alto Maceratese.
This paper presents the intensity distribution reconstructed up to October 20, with an account of the interpretative problems encountered in the process and of the solutions adopted to deal with them.

MACROSEISMIC INVESTIGATION OF SOME PRE- AND INSTRUMENTAL PERIOD EVENTS FROM THE GULF OF CORINTH

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Despite the existence of ample macroseismic intensity data from pre-instrumental earthquakes, their inherent inconsistencies prevail from using them as input to modern seismic hazard techniques. It has often been stressed in the last decade that the intensities of historical earthquakes should be re-evaluated using the available primary sources and according to the currently used intensity scales. This is also the case for events of the early instrumental period, where the use of different intensity scales has produced inhomogeneous macroseismic intensity data sets. In the present study the intensities of historical, as well as early instrumental earthquakes from the area of the gulf of Corinth, Greece, are re-evaluated, and their distribution is derived. These distributions are calibrated to recent events from the same area, in an attempt for a better evaluation of the size of these events. In addition, and since the focal mechanism of the earthquake is directly related to the observed intensity distribution, the possibility of associating the pre-instrumental events to known faults with known focal mechanisms of recent earthquakes is examined.

VERIFICATION OF MACROSEISMIC METHODS ON TWO M=5.2 INSTRUMENTAL EARTHQUAKES IN FRANCE.

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Macroseismic data available for the two most recent M=5.2 earthquakes that occured in the Pyrenees and in the Alps, were analyzed using the Sponheuer and the Levret relationship to estimate depth and magnitude respectively. The excellent agreement between macroseismic and instrumental estimates shows that macroseismic data of historical events may provide the means to lengthen the instrumental catalogue and better constrain the recurrence rates of these two low to moderate seismic rate regions.The Epagny earthquake occured on the 07/15/1996 along the Vuache fault in the French Alps. Instrumental and macroseismic depth estimates both indicate a shallow hypocenter location of around 3-4 km. The question raised by this event is whether the Vuache fault, a conspicous NW-SE trending left-lateral strike-slip fault, is a superficial or a crustal feature. Analysis of macroseismic data available for earlier events (1975,1936,1839) indicates a rather superficial fault generating M=5 earthquakes that originate in the first 4-5 km of the crust. The St Paul de Fenouillet earthquake occured on the 02/18/1996. Its depth is around 10 km, presumably on a ramp structure of the North Pyrenean Frontal Thrust. Again, reasonable agreement between instrumental and macroseismic estimates is found and the study of historical events (1920, 1922) provides important information as to the behaviour of the seismic structures in this part of the eastern Pyrenees.

FROM QUESTIONNAIRES TO INTENSITIES - ASSESSING FREE-FORM MACROSEISMIC DATA IN THE UK

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Questionnaires for macroseismic surveys can generally be categorised into two groups: structured questionnaires, where respondents are given a number of options and have to tick one, and free-form questionnaires, where open-ended questions are answered by the respondents in their own words. Both have advantages and disadvantages. The structured approach is easier for the seismologist to process and is more focussed on the answers he wants to receive. The free-form approach is better at preserving nuances and qualifications to the respondents' answers that might otherwise be lost. Free-form questionnaires can be a lot shorter than structured ones, and it is partly for this reason that practice in the UK since 1974 has been to employ such a questionnaire design; short questionnaires can be distributed widely by being printed in local newspapers. The questionnaires received are then sorted by place, and for each place a synopsis sheet is prepared summarising the reported effects. Intensities are then assigned from the synopsis sheets, with reference back to the questionnaires where necessary. Data are checked using a pseudo-GIS program, and the final maps are prepared with the GMT mapping package.

STRATEGIES FOR THE USE OF MACROSEISMIC INFORMATION IN THE STUDY OF GROUND RESPONSE TO SEISMIC EXCITATION

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Given a magnitude value and an epicentre location what is the intensity to be expected at any selected observation site? Regarding this topic, macroseismic information from Continental Portugal was used to obtain empirical expressions for ground intensity response to seismic excitation. Different approaches were tried and analysed, in order to minimise the uncertainties associated to the corresponding intensity predictions. 1) Fits considering intensity (I) as a function of magnitude (M) and epicentre or focal distance (D), and fits considering I as a function of D for constant M, were obtained. In order to analyse the influence, in regressions results, of the way the input set is selected, given the zone of observation sites and the region of epicentres, different groups of data points were considered in these fits: a) sets with EMS intensity value 1 points, and sets without them; b) sets with different amounts of points of the different intensity values; c) sets with transformed data points, such as points with average distance for given intensity and magnitude, points with hypothetical intensity distributions - intensity considered as varying continuously with distance - for each magnitude and EMS intensity value, and points with the average distances to the isoseismals. 2) I as a function of M fits were computed for data from delimited epicentre areas. Conclusions on the use of these procedures were obtained.

INTENSITY VS CATALOGUES: THE CASE OF THE 1975, JUNE 19 GARGANO (SOUTHERN ITALY) EARTHQUAKE

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Italian seismic Catalogues suffer the problem that intensities of many moderate seismic events (historical and/or present), are often derived from intensity-magnitude relationships, or evaluated only from preliminary sources. In those cases intensities are not assessed by macroseismic studies; consequently, it is possible to find contradictions among different Catalogues, as they often follow different way of intensity assignment. As example, the case of the 1975, June 19 earthquake is presented in this poster. This event occurred in the Gargano area (Southern Italy) with a magnitude M_L=5.1 (ING Seismological Bulletin). The corresponding intensity value reported by the ING Catalogue is I = VIII (computed), while the NT4.1 Catalogue quotes I = VI MCS. Moreover the PFG Catalogue reports this earthquake without intensity. The case of this event is emblematic of a period in which macroseismic studies were not undertaken systematically in Italy. The macroseismic intensity of this event is now assessed by the use of the normal procedures implemented at ING.

PRELIMINARY RESULTS OF THE MACROSEISMIC SURVEY OF THE COLFIORITO SEQUENCE (CENTRAL ITALY)

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The recent seismic sequence occurred in Umbria-Marche region (Central Italy), starting from September 4, 1997, has caused a large amount of damage in a quite wide area. The sequence produced almost five shocks with magnitude higher than 5.0, the largest of them occurred on September 26, UTC 09 :40, M_l =5.8 . The occurrence of many shocks with magnitude higher than 4.0 has contributed to create a damage pattern "in evolution" for over a month. Such seismic behaviour obliged the operators in the field to perform a real-time macroseismic survey to update the data set. One of the major efforts was to discriminate the effects due to each of the largest shocks. In this work we present the macroseismic survey performed during the sequence and some preliminary result inferred from it. The intensity points and macroseismic fields related to the largest quakes of the sequence are presented. Finally some consideration drawn by comparison with instrumental and geological data are shown.

CORRELATION OF SEISMIC INTENSITY WITH FOURIER ACCELERATION SPECTRA

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Many attempts have been made to correlate intensity with ground motion parameters. The correlations with peak amplitudes and duration show great scatter, and till the present there is no equation sufficient enough to determine seismic intensity in terms of physical parameters. We present a method for estimating of seismic intensity in terms of MMI or MCS scale using Fourier amplitude spectra of ground acceleration. The method implies that the severity of earthquake ground motion is determined by spectral amplitudes in relatively narrow frequency band: so-called "responsible frequencies", which decrease (from 7-8 Hz for small intensities to 0.7-1.0 Hz for MMI=VIII-IX) with increasing of the intensity. We examined our model through estimation of prabable intensity using records of recent earthquakes occured in several seismic regions, and prediction of intensity distribution patterns for Coalinga, California earthquake of May 2, 1983, and Spitak, Armenia, earthquake of December 7, 1988. We beleive that seismic hazard maps in terms of intensity scale levels based on the proposed approach would provide a better account for regional features of seismic waves excitation and propagation, as well as for local ground conditions.

CROATIAN MACROSEISMIC DATABASE

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The compilation of the digital Croatian Macroseismic Database is an ongoing project that started in 1995. A total of 426 earthquakes is currently being analyzed. The job is carried out through several stages, each of them corresponding to digitalization of a different input data format (isoseismal- and intensity-maps, intensity point lists, questionnaires, etc.) At first, the 69 isoseismal maps published in the Catalogue of Earthquakes in the Balkan Region have been digitized. The coordinates of the intensity points were assigned to geographic locations (villages, cities, ...) by consulting the data base of latitudes and longitudes of all settlements in Croatia. The 330 existing intensity lists (intensity and name of the place without coordinates) were entered into the database during the second step. The isoseismal maps which were not published so far will be scanned and digitized during the third stage of the project. Main problems encountered so far have to do with digitization from the imprecisely drawn intensity maps based on unspecified cartographic projection, in which case we had to employ various methods of coordinate interpolation in order to be able to assign observed intensity to a geographic locality. Once finished, the data-base will offer possibility to analyze many aspects of the macroseismic field in Croatia (intensity attenuation, distribution of the maximum observed intesities, influence of local soil conditions, etc.).

TESTING THE EUROPEAN MACROSEISMIC SCALE IN THE CASE OF THE 1997, CENTRAL ITALY EARTHQUAKES

Working Group on EMS data of the 1997, Central Italy earthquakes. Reference person: M. Stucchi*
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Damage caused by the 1997, September and October, Central Italy earthquakes was investigated by making use of both MCS and EM intensity scales. Data collected in the view of this test are available for about 70 localities of the most damaged area. These data will be compared against damage data collected by engineers for safety purposes.
The main problems of the survey came from the sequence of damaging events which took place in about three weeks. This situation requested quick, repetitive and therefore not exhaustive investigation, the limits of which are discussed here. The comparison between the intensity values assessed according to the two scales shows interesting insights.

NH3 Earthquake risk mitigation (joint with SE)

04 Active fault and earthquake risk mitigation

Convener: Barka, A.A.
Co-Convener: Stewart, I.S.

A FUZZY SYSTEM TO ASSESS SEISMIC INTENSITY

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We show a technique which allows the encoding and the computer processing of macroseismic effects in order to keep trace of all the steps in the intensity assessment process. It makes use of a multi-criteria decision making algorithm based on the Fuzzy Sets Theory (FST). For two italian earthquakes (the 1919, Mugello and 1920, Garfagnana) we exhaustively classified all the earthquake-related effects found in the available sources, without referring to any macroseismic scale. This classification is based on the decomposition into elementary syntactic components, of any meaningful sentence which can be associated to a set of 5 alphanumerical codes. This method grants the highest adherence of the recorded data with respect to the source contents, since it avoid forced interpretation and the loss of all the information that do not fit into scale descriptions. The availability of the information on computer media allows the reorganization of the data-set in order to group effects which where previously kept distinct but are thought to be equivalent in further processing. The extension of the data-base to a sufficiently large number of earthquakes could allow the definition of a new macroseismic scale on a purely statistical basis.

REVISED MAGNITUDES OF HISTORICAL EARTHQUAKES IN SLOVENIA

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For statistical estimation of earthquake hazard it is of large importance to have unified measure of earthquake size. For historical events no instrumental data are available. Consequently a link between intensity and magnitude is needed. Epicentral or maximum intensity is usually poorly correlated with magnitude, so magnitude formulas based on isoseismal radii are derived. For 18 earthquakes in Slovenia there was isoseismal map available as well as M_{LH} magnitude. Isoseismals were digitized and the relation between magnitude M_{LH} and equivalent radii R of isoseismals were derived:

$$M_{LH} = 2.72 + 1.63 \log R_{VI} \quad (r^2=0.68)$$
$$M_{LH} = 1.08 + 2.32 \log R_{V} \quad (r^2=0.67)$$
$$M_{LH} = 1.14 + 1.96 \log R_{IV} \quad (r^2=0.71)$$

Magnitudes were determined for the events for which isoseismal radii for intensities IV, V and VI were available in the catalogue. The reason for choosing these values was because in 20th century there are not enough data for intensites VIII or VII, which could be used to calibrate magnitude formulas. The strongest earthquake in 20th century was of M_{LH} = 5.7. Revised macroseismic magnitudes for the two strongest events in Slovenia are:

26.03.1511. $M_M=6.8 \pm 0.3$
14.04.1895. $M_M=6.1 \pm 0.2$

FAULT KINEMATICS AND EARTHQUAKE RISK: CHIHSHANG, TAIWAN

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In eastern Taiwan, across the active boundary between Eurasia-Philippine Sea plate, the fault slip was studied during the period 1982-1997 on the Chihshang Fault, a segment of the Longitudinal Valley Fault known active for the last 30 years.
Four sites allowed quantification of fault offsets, because massive buried concrete walls reliably recorded ground deformation. Displacements vectors were measured yearly (1990-1997), in terms of both the amplitudes and the orientations.
At the longest survey site, the total shortening is 29.2 cm in about 11 years. For all sites, the average velocity is 2.4 cm/yr, about one third of the total shortening across the whole Taiwan orogen. Motion vectors trend N120-155°E while the fault strikes N23°E, indicating thrusting with left-lateral component.
The increase in total shortening was nearly linear during the period 1986-1997. After the large 1951 earthquake sequence, creep dominated across this major fault. Minor velocity variations occurred, but no significant decrease in velocity, which would have indicated compressional stress accumulation and increasing seismic risk along the Chihshang Fault, was identified between 1982 and 1991.
Quantitative studies carried out at the outcrop scale along active faults have the potential to allow detection of a decrease in local aseismic slip velocity. Such phenomenon may reflect accumulation of compressional strain across a nearby zone, hence increasing earthquake risk, for the overall deformation is continuing across the seismically active convergent boundary (see Angelier *et al.*, this meeting).

EARTHQUAKE SURFACE FAULTING IN VOLCANIC AREAS: A CASE-STUDY FROM MOUNT ETNA (SICILY)

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Coseismic faulting is generally associated with moderate-large earthquakes (M> 6.2) with extended overall lengths (tens of km) and relevant offsets (in meters). Occasionally ground rupture occurs also with very shallow, low magnitude events (M<4.5) because of peculiar tectonic conditions, for example in active volcanic zones. The present study has allowed the recognition of surface ruptures for a large number of earthquakes occurring at Mt. Etna since 1818 to date by means of a careful search and re-examination of historical sources and recent data. Analysis of surface faulting provided not only a clearer relationship between seismicity and mapped structures to emerge but also a better definition of the volcano!s tectonic framework through the identification of previously undetected, long hidden faults. Critical interpretation of data and ad hoc field investigations allowed also to verify behaviour (kinematics, slip per event, length of rupture) and geometry of seismogenic segments. These findings provide not only effective evidence of ongoing tectonics but also useful elements for seismic risk mitigation. In fact, surface faulting in a densely urbanised area such as the Etnean one is a singular and overlooked source of hazard, destroying houses astride the ground rupture or interrupting essential lifelines (tollway, railway, methane pipeline, etc.).

COULOMB MODELING OF MARMARA SEA EARTHQUAKES SINCE 1700: IMPLICATIONS ON THE EARTHQUAKE HAZARD OF THE ISTANBUL REGION

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Present-day failure stress distribution of destructive earthquakes (I≥VIII, M≥6.3) occurring since 1700 along strands of the North Anatolian fault in the Marmara Sea region is calculated from Coulomb modeling. This is important in particular for the City of Istanbul which is the center of high population (10 Million) and economy. Our investigation is mostly concentrates on the NE-SW trending central Marmara Sea ridge which represents one of the major strike-slip segements. From the historical earthquake records we beleived that the last large earthquake on this ridge was the 1509 earthquake (I=IX-X). GPS measurements illustrated that the slip rate along the northern strand of the North Anatolian fault is more than 10 mm/yr. Our results from the failure stress modeling indicated that the 18th century earthquakes caused stress increase on this ridge, however, this segment was not ready to rupture at that time. If we consider the GPS rate, at present there has been approximately 5 m slip allready accumulated on this segment since the 1509 earthquake. Furthermore, our modeling predicts that this strike-slip segment is most likely to be triggered, if there is a moderate normal fault earthquake in the basins which are bound to this ridge from the east and west.

SEISMIC HAZARD IN THE CAUCASUS REGION

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This study involves the determination of the earthquake hazard in the Caucasus region in probabilistic terms. The area considered is identified as one of the test sites of Global Seismic Hazard Assessment Program (GSHAP). The prominent features of the study are rational delineation of source zones based on different neo-tectonic maps and regionally seismicity; utilisation of spectral amplitude attenuation relationships and; the use of GIS technology in the treatment of data. The neo-tectonic regime and the historical seismicity of the region Several neo-tectonic fault maps and historical seismicity catalogues of the region were guiding tools in the delineation of the following seismic source zones: North Anatolian; Bitlis-Zagros; Black Sea; Pambak-Sevan; Greater Caucasus; Tabriz; Talish; Soltanieh-South Parandak and Arax. The variability of the available neo-tectonic maps introduced uncertainties in some of the source boundaries. For the probabilistic hazard analysis the Poisson model is retained on account of its simplicity, its adequacy for large magnitude events and the fact that the seismic design decisions should be more sensitive to the mean number of events than to their temporal distribution. A sensitivity analysis conducted to assess the influence of the variability of the source boundaries. The earthquake hazard is quantified as contours of iso-peak ground acceleration and iso-spectral acceleration corresponding to different return periods. The results are compared with other studies conducted for the same test area using deterministic, historical-probabilistic and areal-probabilistic techniques.

SEISMIC HAZARD IN THE CAUCASUS REGION

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DEFINING SEISMOGENIC SOURCES FROM HISTORICAL EARTHQUAKE FELT REPORTS

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We present a method to assess the location, physical dimensions and orientation of the source of large historical earthquakes that relies entirely on intensity data. Seismological theory and practice show that the orientation of the seismic source of earthquakes larger than M≥5.5 is reflected in the elongation of the associated damage pattern. A physically plausible and easily understandable way of describing a seismic source is by representing it as a properly oriented "rectangle", whose length and width are obtained from moment magnitude through empirical relations. This rectangle is meant to represent either the actual surface projection of the seismogenic fault or, at least, the projection of the portion of the Earth crust where a given seismic source is more likely to be located. The systematic application of this method to all the M≥5.5 earthquakes that occurred in the central and southern Apennines (Southern Italy) in the past four centuries returned encouraging results that compare well with existing instrumental, direct geological and geodynamic evidence. The method is quite stable for different choices of the algorithm parameters and provides elongation directions which in most cases can be shown to be statistically significant.

SEISMIC HAZARD AND SEISMIC RISK ASSESSMENT FOR SOCHI CITY

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According to the temporary map (scale 1:1 000 000) of seismic zonation of the Northern Caucasian territory, adopted by the Ministry of Construction of Russian Federation in 1994 as a standart, Sochi , the Black Sea shore of Russia, is located in a zone of expected intensity IX on the MSK scale, with average recurrence of such earthquakes once per 1000 years within the area of one thousand sq.km. In comparison with the previous standart map of seismic zonation of the former USSR, the city seismicity was increased by 2 grades of intensity scale. In order to verify the seismic hazard level the schematic map (scale 1: 100 000) of tectonic faults was compilied with the use of space photography. As 30% of the mountain area of the city is exposed to landslides, mudflows, avalanches, the detailed engineering geological study was carried out. Seismic risk (ecomonic and social losses) was computed with taking into account the verified seismic hazard level and other geological processes. The corresponding maps of total direct losses caused by damage to residential buildings from scenario earthquake, summary direct losses taking into account secondary technogenous processes, as well as of specific social losses (number of people killed and injured per unit square) were compiled on the scale 1:50 000. The obtained results allowed to estimate the insurance rates for Sochi City.

NON-TRADITIONAL ASPECTS OF SEISMIC HAZARD IN THE ZONE OF ACTIVE FAULTS WITHIN THE RUSSIAN PLATE

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Study of spatial migration of earthquake epicentres with M>3.0 for a phase 1963-1992 years has shown that seismoactive faults of Fennoscandia extend to Russian plate. Tectonic zones of the Baltic Shield and Northern part of the Russian plate create a complicated pattern in space and a combination of faults, grabens, horst, forming a peculiar tectonic framework of structures successively evolving in time represent. These zones are characterized by inheritance in space, re-iteration and association with weakened zones of general NW and NE direction from Late Archean to present. The epicentres of earthquake form the belt extending in NE and NW directions. These direction conform with faults dividing Baltic Shield and Russian Plate into separate tectonic bloks.The investigations carried out by the authors, has shown, that in Archangelsk's region these structures are ruinous for marine stars in Onega and Dvina Gulfs, fishes in Lekshmozero. The main causes of the phenomena of earthquakes influence on the environment are not clear. Some of causes are: horizontal and vertical migration of the geochemical elements, the fluides of depth gases, fluctuations of electro-magnetic fields and contamination by toxic organic matter, is intrinsic in basement and sedimentary rocks of the Russian Plate, in the zones of seismoactive faults. The main stream of gas is moving through the faults and by the zones of fracture. The important role in this process the recent tectonic movements and migration of earthquake epicentres play.

FAULT-FRAGMENTS AND RELATED ACTIVE DEFORMATION: IMPLICATIONS FOR THE SEISMIC HAZARD ASSESSMENT

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We study examples of coseismic surface faulting in different tectonic regions and it appears that in many cases, earthquake faults are not characterized by straightforward clearly expressed surface ruptures. In order to address this problem we use the fault fragment model which refers to the minimum fault-area for which the coseismic deformation is visible at the ground surface (Meghraoui and Camelbeeck, 1996). The maximum fragment size is the fault rupture for which $L^* = H/k_1$ (H is seismogenic layer depth, k_1 constant strain level) holds, reaching ~ 10 km rupture length and producing 10^{17} - 10^{19} N.m. of moment-earthquakes. Furthermore, the size of fault fragments coincides with the dimension limit at which the self-similar behavior of earthquakes mechanics changes, i.e., a break in self-similarity at the limit between small and large earthquakes. The fault fragment may represents the basic crustal element by which the seismic strain is released in active zones with distributed deformation. In this context, the fault emergence and visibility might be controlled by local tectonic pattern (block tectonic), inherited and new structures, fault geometry and dimensions and related earthquake-size. In many active zones, the seismic hazard assessment depends on a complete inventory of fault fragments capable of producing moderate-sized but damaging earthquakes.

PROGRAM OF THE NUCLEAR POWER STATIONS SEISMIC PROTECTION IN THE UKRAINE

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The seismic situation in the Ukraine is considered as calm in general. However, it territory contains the seismic active M 6-7 with the local sections M 8 zones. There are Crimea zone, Carpathy, all south-west part of Ukraine, seismic active zones of the East-European platform boundary, Donbass. The large industrial units, in particular, the nuclear power stations (NPS) have been built there and in other seismic active regions. Ukrainian NPS are usually situated near large cities and it damages could cause the essential economic disasters and environment catastrophes. In this sense, the possible earthquakes are very strong hazard. Therefore, the permanent seismic observations and corresponding NPS protection have the most importance. The complex program to develop the national system of the seismic observations and to raise the population safety in the seismic hazardous regions has been worked out in the Ukraine. In particular, the program foresees to re-supply the NPS with modern seismic control equipment. In frame of that program, the State Scientific Industrial Association "Metrology" (Kharkov) develops, manufactures and tests the various types seismic sensors intended for operation at the NPS prediction systems. To verify those sensors, we have developed pendulum calibrator allowing to attest it directly at the station. It is foreseen to equip all the Ukrainian NPS with such technique. As a result, the NPS reliability and safety will be improved.

TWO-WAY COUPLING BETWEEN ERUPTIONS AT VESUVIUS AND SOUTHERN APENNINE EARTHQUAKES BY ELASTIC STRESS TRANSFER

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During the past thousand years, eruptions of Vesuvius have often been accompanied by large earthquakes in the Apennine chain 50-60 km to the northeast. Statistical investigations had shown that earthquakes often preceded eruptions, typically by less than a decade, but did not provide a physical explanation for the correlation. We explore elastic stress interaction between earthquakes and eruptions, under the hypothesis that small stress changes can promote events when the Apennine normal faults and the Vesuvius magma body are close to failure. We show that earthquakes can promote eruptions by compressing the magma body at depth and opening suitably oriented near-surface conduits. Voiding the magma body in turns brings these same normal faults closer to Coulomb failure, promoting earthquakes. Such a coupling is strongest if the magma reservoir is a dike oriented parallel to the Apennines and the near-surface conduits and fissures are oriented normal to the Apennines. This preferred orientation suggests that the eruptions issuing from such fissures should be most closely linked in time to Apennine earthquakes. We use our modeling results to select those earthquakes and eruptions for which the coupling is favored and we performed a new statistical analysis, which yields a better correlation with respect to the Marzocchi et al.'s [1993] results.

ACTIVE TECTONIC STRUCTURES IN THE PADANA-PLAIN: NEW DISCRIMINATION STRATEGY FROM A JOINT STUDY OF GEOMORPHIC AND GEODETIC LEVELING DATA

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We compared geomorphic anomalies with a wave-length comparable to that of tectonic structures of crustal significance (10-30 km), with elevation changes from successive leveling surveys (1985-1953, Italian first order network) for two sample areas of the Padana Plain, located near Mantova and NW of Treviso. Both areas are characterised by clear anomalies in the drainage pattern, which is highly sensitive to vertical motions. The analysis of the leveling data shows differential elevation changes in agreement with the strain field inferred from geomorphology. For each area we estimated the geometric and kinematic parameters of the crustal fault that fits best the observed geomorphic and geodetic anomalies. To address the question of whether the fault is mainly creeping, as suggested by the paucity of background seismicity, or potentially seismogenic we compared the strain rate inferred from geodesy with that derived from geomorphology. We found that the geodetic rate (a) accounts for only a small fraction of the rate detected from geomorphology, and (b) does not seem large enough to induce the observed perturbations of the drainage. To explain the strain surplus inferred from geomorphology we suggest that the hypothesised faults could generate infrequent earthquakes up to M 6.2-6.5, which would induce the observed instantaneous yet localised diversions of the water flow.

MAPPING SUBSURFACE FAULTS USING REALTIVE LOCATIONS AND FAULT PLANE SOLUTIONS OF MICROEARTHQUAKES

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Relative locations of clusters of similar microearthquakes can be determined with uncertainties less than 10 m. The mean distance of a group of earthquakes from the best fitting plane through the group is often comparable to the relative location uncertainty of individual events. A simple interpretation of the best fitting plane through a dense cluster of earthquakes is that it coincides with the common fault plane of the group. Fault plane solutions provide independent estimates of fault orientations. These methods have been applied to tens of microearthquake clusters in Iceland. In the transform zones in north and south Iceland the fault orientations determined in this manner agree closely with field observations. Near the Hengill triple junction and volcano complex in SW Iceland the pattern is more complicated and fault orientations often deviate markedly from fault aspects determined by surface observations.

SEISMIC HAZARD ASSESSMENT BY USING ACTIVE FAULT DATA

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The Map of active faults of Eurasia, 1:5000000, was compiled as a part of the ILP Project II-2 "World map of major active faults". To find the general criteria of intensity of active faulting, the components of tensor of recent deformation rates were calculated and mapped in the Alpine-Himalayan collision belt by using active fault data. Areas of concentration of the deformation are seen in the maps. They form wide zones along the recent plate boundaries, in their junctions, and along some other active fault zones of the higher seismicity. Active faults, differentiated by their activity, were used (together with some parameters of seismicity) for mapping seismotectonic domains of the northern Eurasia and calculating their seismic potential [Shebalin et al., 1995]. The map of the domains have been used for calculating strong motions and general seismic zoning. To detailize the seismic hazard assessment, active tectonics of the earthquake source zones of the Arabian-Caucasus collision region were studied. Tectonic regularities of crustal seismicity are not limited by interaction of plates and crustal blocks. Our studies in the North Anatolian fault zone showed that average rate of the seismotectonic deformation (during the 500-year seismic cicle, not the XX centure) is higher in some sites than average rate of the plate interaction motion because of higher vertical component of the seismic displacements. Thus, some local factors increase rate of the elastic deformation and produce additional vertical seismic displacements. These sites are located in the ophiolite zones. We found concentration of strong earthquake epicentres in the ophiolite zones in all the Arabian-Caucasus collision region. Perhaps, the additional vertical seismic displacements depend on stress, produced by increase of volume of peridotites and basalts because of mineral transformations by water circulation in the fault zones.

PALEOSEISMOLOGICAL INVESTIGATIONS ALONG THE MOSCARELLO FAULT, MT. ETNA VOLCANO (SICILY)

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A program of trench investigations and geomorphological analyses has been recently initiated at Mt. Etna, whose eastern flank is affected by very active, mainly NNW-SSE-striking, normal faults, the "Timpe" fault system, which represents the northermost inland extension of the Malta Escarpment. This study focuses on the Moscarello fault, which displaces Late pleistocene-Holocene lava flows and alluvial fan deposits for a length of ca. 10 km. The maximum observable throw, more than 125m in less than 100,000 years, is attained in the northern sector of the fault, that borders the Fondo Macchia tectonic basin. This depression has hosted some of the largest earthquakes occurred in the volcanic area, with generally shallow sources and macroseismic intensities reaching the IX-X degree MSK. Coseismic surface faulting, up to 6 km long and with 30 to 90 cm of vertical offsets, was associated to the 1855, 1865, 1911 and 1971 earthquakes. Hence, two trenches were excavated along the 1971 coseismic scarp at Fondo Macchia, aiming at reconstructing the fault behaviour on a longer time-span and at better understanding the relationship between the "Timpe" system and the active Malta escarpment, suspected source of the major earthquakes in SE Sicily. Here, the first results of stratigraphic and geomorphological analyses and radiocarbon dating are presented.

NH3 Earthquake risk mitigation (joint with SE)

05 Landslide hazards in seismically active regions

Convener: Wasowski, J.
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EARTHQUAKE RELATED GRAVITATIONAL PHENOMENA IN THE UMBRO-MARCHE APENNINES (CENTRAL ITALY): THE CASE OF THE SEPTEMBER - NOVEMBER 1997 SEISMIC EVENTS

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During autumn 1997 a very strong sequence of seismic events struck a vast area in the Umbro - Marche Apennines, an east verging thrust belt made up in Neogene times and subsequently dislocated by normal and transcurrent faults which are still active. From September 26 (at 0.33 GMI) to mid-November, five main shocks (with magnitude ranging between 5.5 and 6.0 MW) and a large swarm of minor shocks caused 12 deaths and detroyed or heavily damaged a large number of building including historical monuments of inestimable value such as the monastery of S. Francesco in Assisi. The epicenters were located around the Colfiorito basin, an intermontane tectonic depresion berdered by NNW - SSE trending active normal faults. The earthquake produced wide spread surface effects including ground fracturing and faulting, debris compaction and a large number of gravitational phenomena of different type and size. Rapid mass movements such as rock fall, debris fall and debris flow were directly triggered during the earthquake shaking, both by ground fracturing and oriented accelerations, while slide phenomena in clay-rich materials were activated later, mostly after heavy rainfall infiltration through open gran fractures. Also deep seated gravitational deformation phenomena on limestone slopes, such as at Mt. Frascare and Mt. Fema, were ractiveted by the earthquake shocks, even at some distance from the epicentral area. All the above phenomena have been examined and mapped in order to compare their distribution pattern with that of the isoseismal lines. The resalting data may be useful for future land planning and management in the area.

RECONNAISSANCE AND DESCRIPTION OF LANDSLIDE DAMS OF SEISMIC ORIGIN IN SOUTH-EASTERN SICILY

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Among the secondary effects induced by seismic ground shaking, this paper focuses on the analysis of earthquake-triggered landslide dams. When an earthquake occurs and is strong enough to trigger slope movements, the blockage of a river is frequent in narrow, steep valleys; consequently, an impoundment upstream of the landslide forms and, if the dam does not fail, is gradually silted up.
A sample of eight earthquake-triggered landslide dams in SE Sicily is presented and discussed in this paper. The origin of these landslides is most likely related to the occurrence of the strong earthquakes which periodically shake this sector of Southern Italy: three seismic events having intensity equal or greater than X in this millennium, and an unknown, but presumably conspicuous, number of comparable events in previous times.
Each landslide dam was analyzed in relation to local geology, type and dimensions of slope movement, presence and characters of silting up deposits, conditions at present. The list of relevant question proposed by Schuster and Costa (1986) and the classification scheme proposed by Costa and Schuster (1988) were followed, in order to obtain descriptions of the landslide dams as complete and consistent as possible. A sketch of the overall characteristics of these dams is eventually given.
The information coming from this work could be used for a twofold purpose: 1) to develop a database of earthquake-triggered landslide dams in SE Sicily; 2) to evaluate the risk, if any, related to the actual dams. Furthermore, the analysis of landslide dams distribution and characteristics in relation to main seismogenic areas could provide useful information in the attempt of identifying the most typical geomorphic and geologic conditions under which, should a moderate to strong earthquake occur, landslide dams could more likely develop.

GENESIS OF THE SEISMODISLOCATIONS IN THE EPICENTER OF THE RACHA EARTHQUAKE

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(1) The destructive Racha earthquake occured on April 29, 1991 in the northern part of Georgia. The earthquake of magnitude M=6.9 and intensity in epicentre IX (MSK scale) had a focus at about 5km depth. (2) Analysis of seismodislocations emerged in the epicentral area showed that they are mainly rockfalls, landslides, rock avalanches and displacements in unstable degradational slopes. Much rare are small amplitude fractures and cracks, especially of strike-slip and combined character (reverse fault-shear, normal fault-shear, etc.). The latter are most frequently grouped in N or NW direction. For the earthquake of such great energy the secondary dislocations turned out to be dominating., whereas the primary ones have subordinate character. This phenomenon may be explained by intensely dissected mountainous relief previously prepared by tectonic and erosional processes and enhanced by superimposing the gravitational effect. (3) The concentration of landslide-avalanche manifestations along the zone of the deep fault, separating the stable Georgian block from the folded zone of the Southern slope of the Greater Caucasus, in our opinion, may be explained by complex kinematics of the collision of the two opposite-directed mass movements separating here structural-tectonic domains of the Greater and Lesser Caucasus.

WATER BALANCE MODEL OF A LANDSLIDE DAMMED LAKE IN THE ANDES OF NW ARGENTINA (26°S, 66°W)

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A water balance model has been applied to a paleolake existing about 35 kyr BP in the Valles Calchaquies of northwest Argentina. This lake resulted from damming of the Rio de las Conchas by a catastrophic landslide in the tectonically active transition between the Sierras Pampeanas and eastern Cordillera geologic provinces. Similar to other ephemeral lakes in northwest Argentina the existence of this lake coincides with the Pleniglacial wet period (40 - 25 kyr BP). Field observations indicate that the disappearance of the lake was due to clastic infill rather than increased evaporation. Paleoenviromental reconstructions based on varved lake deposits provide detailed information on the seasonality of river discharge and sediment sources within the basin and are used to define boundary conditions for the model. Based on these parameters, different scenarios were developed for climatic conditions consistent with the existence of the lake. A higher precipitation must coincide with increasing cloudiness and a weaker wind-regime combined with lower temperatures in order to establish and maintain such a lake. The model, adapted from Blodgett et al (1997), incorporates mean cloudiness and wind speed as well as temperature and precipitation in estimating evaporation and resulting lake levels. Additionally, the model now incorporates new modules accounting for spatial variation of rainfall and distribution of source rocks in the catchment area.

LARGE APENNINE LANDSLIDES ALONG ITALIAN ADRIATIC FOREDEEP STUDIED BY L-TRANSFORMS (VISCO-ELASTIC DOMAIN)

The Adriatic Slope of the Apennine Range is characterised by a number of large landslides - permanently affecting rural lands, roads, towns and also rivers - in particular along the Adriatic Foredeep, marked by a continuous gravimetrical through, modulated by three gravimetrical highs, located near the geomorphological evidences of Monte Conero, Montagna Maiella and Monte Vulture..
In the frame of a broader geophysical research, seismo-genetic visco-elastic geostructures have been suggested, which are able to transfer seismic energies to the Earth surface, owing to viscous connections with deep, thin viscous geostructures, squeezed by African Plate effects, also according to the secular anticlockwise rotation of the Italian Penin-ula. These basic models are suggested by gravimetrical maps, filtered at sub-regional scales: their squeezing appears to be one of the major geophysical causes of landslide generations, owing to both the nearly continuous modifications of local slopes at the surface and the triggering effects caused by very frequent earthquakes.
L-Transform methods help to deal with different possible (also underhand) approaches, which induce unstable masses located upon those Apennine slopes to start their dangerous trends.

EARTHQUAKE-INDUCED LANDSLIDES IN SAGUENAY LOWLANDS (QU$_f$BEC, CANADA) : IMPACT OF THE 1663 CHARLEVOIX EARTHQUAKE

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Our research work on physical impacts of the July 1996 Saguenay deluge has led us to define a 14C-based reconstruction of the regional dynamics of landslides. Our first set of dates indicates that distinct generations of landslides have dissected postglacial marine terraces during the last millennia. Ages related to the most recent period of extensive landsliding range from 320 ± 60 BP to 240 ± 40 BP ; once calibrated into calendar years (1627 - 1677 cal AD), they are centered around the well-known February 1663 earthquake in Charlevoix, 100 km away from the Saguenay region. Data from tree-ring analysis of tree trunks buried in landslide sediments strengthen the idea that the 14C-dated landslides were triggered by the 1663 major seismic event. Precise dating of a large number of landslides in the Saguenay region provides new insights on the relative importance of different natural causes for slope failures in postglacial marine clays. It also contributes to establish the distribution of landslides induced by the 1663 earthquake. In addition to the Mauricie and Charlevoix regions where large landslides have previously been linked to the 1663 event, the Saguenay lowlands are another region where this M=7+ (estimated) earthquake had strong geomorphic impacts.

Surface effects induced by the 26.09.97 Umbria –Marche earthquakes

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In the paper the surface effects induced by the 26/9/97 earthquakes which stroke Umbria and Marche regions (central Italy) will be described and discussed. The two main events occurred at 00h33m and 09h40m UTC, with magnitude M_d equal to 5.5 and 5.8 respectively (ING, 1997).The authors have examined a wide area (about 700 Km^2) around the two epicentral zones. The effects have been catalogued in: rockfalls and landslides, subsidence phenomena, hydrological phenomena, ground fractures. Frequent rockfall phenomena along the sides of the roads have been observed. Huge phenomena occurred in Stravignano-Bagni and Sorifa towns, where volumes up to thousands of cubic meters failed in the Travertino rock formation. Three major subsidence phenomena will be discussed, which occurred at Bagnara and Le Moline towns and at Acciano Dam. Ground fractures have been observed all over the area; their areal distribution, length and orientation have been studied, and correlations with the surface faulting systems have been found out.

SPATIAL HAZARD ASSESSMENT FOR LANDSLIDES UNDER SEISMIC CONDITIONS

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The stability of natural slopes is influenced by geographical, geological, geomorphological, geotechnical and hydrological factors. Over the last fifty years or more, a great deal of research has been carried out in many countries to understand the fundamental causes and mechanisms of slope instability. Methods of geological and geotechnical modelling and analysis have been developed to understand landslides which have occurred and to predict future instability. The roles of triggering factors such as deforestation, development, rainfall and earthquakes have been explored. It is now acknowledged widely that accurate prediction of slope stability is often difficult due to uncertainties concerning geological details, geotechnical properties as well as triggering factors. Seismic effects of triggering landsliding are highlighted in this paper.

In this paper, attention is drawn to hazard assessment facilitated by GIS-based techniques for mapping and risk assessment. So far this approach has been validated for rainfall-triggered landslides in the Illawarra region. It is argued in this paper that a similar approach can be developed for seismically active regions. Spatial distribution of landsliding can be studied in a rational and systematic manner and thus spatial 'probabilities of landsliding can be correlated to geological and geotechnical factors. The methods and approaches discussed here enable assessment as well as updating of hazard.

DEVELOPMENT OF A LANDSLIDE HAZARD MAP FOR NORTHWEST ARGENTINA

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A map of landslide hazards is produced for northwest Argentina which provides a synthesis of geologic, paleoclimate and modern meteorological studies in this area (as presented in this session). These complementary studies have described geological preconditions for landslide occurrence, source lithologies, seismic triggers and required relief contrasts as well as indications of additional, more frequent events in the past resulting from moister climates. The present synthesis incorporates these results with modern measures of rainfall provided by satellite-based retrievals and supported by ground station records to determine regions of particular landslide susceptibility due both to existing preconditions and likelihood of additional rainfall triggers. Relevant datasets are compiled and analysed within a Geographic Information System (GIS) focusing on topographic analysis (slope and relief), rainfall (ground station and satellite) and lithology (field observations and Landsat TM classification). This analysis identifies areas of potentially higher susceptibility and impact due both to rainfall distribution and existing development.

DEEP-SEATED GRAVITATIONAL SLOPE DEFORMATIONS (DGSD) AS A NATURAL LABORATORY OF BRITTLE ROCK DEFORMATION - IMPLICATIONS TO ROCK SLOPE HAZARDS.

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In the central mountain chain of the Eastern Alps slope instabilities of Sackung type morphology are common phenomenons. Three general types of Sackung, interdependent on both host rock lithologies and inclination of the main foliation, can be distinguished. Thereby, surface slope failure geometry do attest normal fault tectonics. Associated subsurface structures indicate deformation of affected host rocks close to pure shear as well as close to simple shear regime. Formation of new generated fractures in cooperation with reactivation of preexisting joints provide penetrative and also deep reaching relaxation of mountain ridge brickwork. Ongoing gravitational creep of relaxed rock masses is responsible for excessive processes of erosion, increasing provocation of large scale rock avalanches and torrentiality. Especially in the area of DGSD rock fall events are frequent. Therefore, these movable rock masses triggering to DGSD do represent sources of several mass movement hazards and simply can be aktivated by earthquake events.

IMPORTANT BOUNDARY CONDITIONS CONTROLLING ROCK-AVALANCHE DISTRIBUTION IN SEMI-ARID NW-ARGENTINA

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Landsat TM analysis of the semi-arid Puna and adjacent Eastern Cordillera and Sierras Pampeanas (24° - 28° S) has revealed the existence of at least 53 rock-avalanche deposits with volumes in excess of 10^3 m^6 formed by the collapse of entire mountain fronts. Their spatial distribution is not random, but show remarkable clustering along neotectonic active mountain fronts. Detailed field studies reveal five principle controls on the distribution of these events. The source area of the rock avalanches has two topographic constraints, vertical relief contrasts have to be higher than a threshold of 400 m (I) and the slope inclinations have to be steeper than 20° (II). Furthermore, rock avalanches occur in three types of lithology (III), granites, low-grade metamorphic rocks, and coarse clastic sediments. Structural controls (IV) are very important. All avalanche deposits occur along neotectonically active mountain fronts. In addition planar structures like bedding planes, exfoliation joints, minor faults and foliations dip in all cases toward the valley. Finally, major slide clusters occur along mountain fronts which experienced a Quaternary reverse-fault reactivation of former strike-slip faults (V). Although three of the major slides are about 30 ka old and may correspond to a more humid interval in South America, the trigger mechanism for the majority of these landslides is interpreted to be seismic shaking in accordance with important landslide events elsewhere.

ASSESSING HAZARDS FROM SEISMICALLY TRIGGERED LANDSLIDES: AN OVERVIEW OF THE STATE OF THE ART

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Landslides are a major cause of damage in most large earthquakes. Triggered landslides commonly damage and destroy homes and other structures, block roads and rail lines, sever pipe and power lines, and dam streams and rivers. Over the past 20 years, our understanding of earthquake-triggered landslides and their impact has increased greatly. In particular, significant progress has been made in (1) characterizing the environments that are most susceptible to seismically triggered landslides, (2) quantifying the relative abundance of various types of landslides likely to be triggered, (3) documenting the threshold shaking conditions needed to cause failure, and (4) developing methods to model coseismic landslide deformation. But even in light of this progress, several fundamental advances are still needed to more accurately predict where and in what conditions earthquakes are likely to produce widespread damaging landslides. Some innovative research aimed at advancing the state of knowledge includes (1) developing simplified methods to model earthquake-triggered landslide movement, (2) conducting field experiments by permanently instrumenting landslides to directly measure coseismic landslide behavior, and (3) developing methods to use high-resolution, computer-based geographic information systems (GIS) to quantitatively assess and map regional seismic landslide hazards.

OCCURRENCE AND EVALUATION OF LANDSLIDES GENERATED BY EARTHQUAKES

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Seismic shaking is one of the main agents generating landslides, and large earthquakes may produce tens of thousands of landslides, dislodging more than a billion cubic meters of material from slopes and causing significant economic losses and casualties. These landslides may be classified into three main categories: The first includes such highly disrupted landslides as rock falls and debris slides, which occur on steep slopes and are overwhelmingly the most abundant. The second category involves deeper-seated and more coherent bodies such as rotational slumps and translational block slides, which may cause considerable damage largely because of their occurrence on gentler slopes. The third category includes partly to completely liquefied masses, such as lateral spreads and mud flows, which may originate on still gentler slopes. The total area affected by landslides in earthquakes with magnitude, M may be approximated by the regression relation $\log_{10}A = M-3.46$, where the area, A is in km^2. The total volume of landslide material may be approximated by the relation $\log_{10}V = 1.45M-2.50$, where the volume, V is in m^3. The susceptibility of slopes to failure may be evaluated using either geologic criteria or engineering slope-stability analysis. For the most common types of landslides, the most important geologic characteristics are degree of weathering, strength of cementation, fracture spacing and openness, and ground-water conditions.

LANDSLIDE HAZARD MANAGEMENT AND PREDICTION OPTIONS: SOME STRATEGIES FOR THE SIKKIM HIMALAYA, INDIA

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Sikkim Himalayan terrrain is frequently affected by the single worst natural hazard manifested as landslides. The causes are characteristic fragile host mountain terrain accompanied with adverse natural events as well as anthropogenic activities. Himalayan region in general is considered to be seismically active. Physiographically more sensitive zones with slope instabilities undergo high intensity rainfall. The most common landslide triggering factor here is the cloud burst which is highly concentrated rainfall over a small area lasting a few hours. The earthquake tremors with epicentres in North Eastern states preceeding some of the earlier events are believed to have caused instabilities which caused landslides later on during high intensity rainfall. Therefore, the role of earthquakes as an indirect cause contributing to such events of mass movements leading to loss of lives and other related impacts have been analysed. This study is aimed at evolving risk management and prediction strategies taking into account assessment of some of the past events of significance with the consideration of triggering causes preceding these. The general geological set-up, meteorological, seismological and geo-environmental factors have been correlated. Following are the overall envisaged approaches: (i) Identification of landslide susceptibility zones for sample areas based on high resolution remote sensing data, topographic maps and ground level observations. (ii) Identifying areas and meteorological situations that favour the occurrence of cloud burst. (iii) A correlation of susceptibility zones with the triggering events in retrospect to establish threshold factors for prediction. (iv) Strategies to prevent and reduce the damages in the disaster. The study also aims to demonstrate the utilization of Geographical Information System (GIS) based approach for an effective collection, analysis, storage and display of information for the management and prediction of this natural hazard. The scope of application remains wide where this shall be of assistance to the planners, policy makers and administrators towards hazard prediction, early warning, control and management.

HYBRID PROBABILISTIC-DETERMINISTIC APPROACH FOR MAPPING LANDSLIDE VULNERABILITY TO EARTHQUAKES USING GIS TECHNIQUES

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Landslides triggered by earthquakes represent a common phenomenon, recent experiences (Umbria-Marche event, 26/09/97) show how the role of unstable slopes is fundamental for post-earthquake reconstruction and for land use planning. The most common approach used to determine slope vulnerability to a seismic event is to calculate the critical horizontal acceleration (kc) which can trigger the terrain, using deterministic methods. For thin soil layers on hillside slopes the infinite slope model is commonly used for individual slopes, but recently it has been applied over large areas, especially after the increasing role played by the Geographic Information Systems (GIS), whose importance is mainly due to their capacity of storing, updating and analysing data in relatively short time. The application of deterministic models often implies the detailed knowledge of geotechnical, geometric and hydrogeological parameters and for this reason the application over large areas can lead to errors, as the outcome is represented by unique values of Kc. To overcome this limitation a solution can be a parametric analysis, that is using geotechnical parameters varying from a maximum and a minimum value and assuming either dry or variable saturation condition degrees. The suggestion here proposed is the adoption of statistical techniques to obtain a distribution of Kc values. A Monte Carlo simulation is proposed adopting probabilistic distribution of geotechnical, geometric and hydrogeological parameters, through the following phases: identification of landslide mechanisms, selection of slope stability method, selection of terrain unit, input data layer preparation, analysis. The procedure was applied on an area of the Serchio river (Toscana, Italy).

CLIMATE-TRIGGERED VARIATIONS IN DIATOM ASSEMBLAGES IN A PLEISTOCENE LANDSLIDE-DAMMED LAKE IN THE VALLES CALCHAQUIES, NW ARGENTINA (26°S, 66°W)

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Two massive rock avalanches dammed a lake in the Valles Calchaquies, NW Argentina about 35 kyr BP. In order to evaluate climate as a major influential factor in rock-avalanche development, varved deposits of this lake have been studied in great detail. The 1 to 10-mm-thick varves consisting of fine-grained detrital material are topped by thin layers of pure white diatomite. From diatom analyses we infer a significant impact of climate-triggered hydrological and chemical changes on the ecology of the lake system. During the wet years characterized by an enhanced influx of reworked Fe-rich muds, the diatom flora was dominated by the planktonic species *Cyclotella agassizensis* Hakansson. During the following drier years, *Aulacoseira granulata* (Ehrenberg) Simonsen were abundant. For these dry years increasing numbers of the morphotype *Aulacoseira granulata f. curvata* are observed. According to modern ecological observations of similar species, we interpret the increased Fe-supply as the most likely trigger for the dramatic increase in the *Cyclotella* population. The shifts towards higher numbers of the curved *Aulacoseira* indicates gradually decreased Si supply in the water body during the dry years. These climate-triggered changes in the lake ecology show mean periodicities of 3-5 and 10-13 years suggesting an influence of the El Nino/Southern Oscillation teleconnection and tropical Atlantic sea-surface temperature dipole. These climate oscillators also influence modern rainfall but with different intensity. The reconstruction of this interannual rainfall variability is of great importance in the assessment of the role of climate in landslide generation. Moreover, the dynamics of the paleo-lake provides important constraints for a lake balance model (presented in this session).

EARTHQUAKE RELATED LANDSLIDES IN GREECE

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The area of Greece is the most seismically active in Western Eurasia. A large number of strong earthquakes have been reported to cause landslides and other ground failures. An effort has been made to compile data on earthquake related landslides in Greece from the antiquity up to the present. Preliminary results have been obtained on the landslide characteristics, the maximum epicentral distance, D, at which they may occur as a function of the earthquake magnitude, M, and the frequency of landslide occurrence as a function of M. The results are compared with those reached at other regions of the world and are discussed as for their value for seismic and landslide hazards assessment.

A SEISMIC LANDSLIDE SUSCEPTIBILITY RATING OF GEOLOGIC UNITS BASED ON ANALYSIS OF CHARACTERISTICS OF LANDSLIDES TRIGGERED BY THE JANUARY 17, 1994, NORTHRIDGE, CALIFORNIA, EARTHQUAKE

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One of the most significant geologic effects of the 17 January 1994 Northridge, California, earthquake (M = 6.7) was the triggering of thousands of landslides over a broad area. Some of these landslides damaged and destroyed homes and other structures, blocked roads, disrupted pipelines, and caused other serious damage. Analysis of the distribution and characteristics of these landslides is important in understanding what areas may be susceptible to landsliding in future earthquakes. We analyzed the frequency, distribution, and geometries of triggered landslides in the Santa Susana 7.5' quadrangle, an area of intense seismic landslide activity near the earthquake epicenter. Landslides occurred primarily in young (late Miocene through Pleistocene) uncemented or very weakly cemented sediment that has been repeatedly folded, faulted, and uplifted in the past 1.5 million years. The most common types of landslides triggered by the earthquake were highly disrupted, shallow falls and slides of rock and debris. Far less numerous were deeper, more coherent slumps and block slides, primarily occurring in more cohesive or competent materials. The 1,562 landslides in the Santa Susana quadrangle were divided into two samples: single landslides (1,502) and landslide complexes (60), which involved multiple coalescing failures of surficial material. Landslide morphologies were described by computing simple morphometric parameters (area, length, width, aspect ratio, slope angle). To quantify and rank the relative susceptibility of each unit to seismic landsliding, we calculated the proportional landslide area and frequency of landslides within each geologic unit. Susceptibility categories include Very High Susceptibility (> 5% landslide area or > 30 ls/km²), High Susceptibility (1-5% landslide area or 10-30 ls/km²), Moderate Susceptibility (0.5-1% landslide area or 3-10 ls/km²), and Low Susceptibility (< 0.5% landslide area or < 3 ls/km²).

EARTHQUAKE-INDUCED GROUND FAILURES IN ITALY

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ABSTRACT.
The National Catalogue of the ground Displacements Induced by strong Earthquakes in Italy (C.E.D.I.T., release 1.1), is here presented. The catalogue contains information regarding the soil displacements triggered by the earthquakes occurred in Italy in the last millennium with a nominal epicentral intensity equal to or greater than 8 in the MCS scale. The catalogued effects are the following: landslides, liquefaction, surface faulting and fractures, topographic changes of the ground level (subsidence, settlements, and so on). Each effect is described in terms of seismological parameters of the triggering earthquake, site coordinates and administrative code, lithology and kinematics type of phenomenon. The historic or scientific source referring to the effect is always preserved, to allow a retrieval of the deduced phenomena.

SEISMICALLY-INDUCED LANDSLIDE DISPLACEMENTS: A PREDICTIVE MODEL.

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ABSTRACT.
A model for predicting earthquake-induced landslide displacements is shown. The model has the purpose to provide a simple way to predict the coseismic displacements affecting a sliding mass subject to earthquake loading. Critical accelerations are investigated with regard to the mechanical soil properties, pore pressure distribution and geometrical configuration of the slopes. The acting seismic forces are investigated in terms of energy radiation of the source, propagation and site effects, based on 190 accelerometric recordings coming from 17 Italian earthquakes with magnitude between 4.5 and 6.8.
The implemented displacement model is the well-known Newmark sliding bolck model, improved by taking into account the degradation of the mechanical soil caracteristics.

STUDYING THE SLOPE-PROCESSES IN SEISMIC-ACTIVE REGIONESWITH THE HELP OF REMOTE SENSING

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This method was used and examined at 4 objects in seismic- active regions in Middle Aisa and the Caucasus alpine belt. In the region of Haitskoye earthquake of 1949 in Middle Aisa the mud-rock flood over-covered the settlement Haite. The heigint sediment there is about 40m. After the earthquake in the North Caucasus in 1970 the mudstream damed river Sulak. In Dagestan near settelment Mochok was formated the mountain lake with the depth of 70m as a result of movement of the huge masses of rocks. The formation of mud-torrent was stopped by engineer-geological works.In the region of Djavskoye eathguake in South Osetya in 1991 river Patsa was damed by the large landslide and formated lake was a real danger for the settlement Tshinval. In all these cases theodolitic and field survey was made and aerial survey materials obtained before the earthquakes and after them were also deciphered.

THE ROLE OF CLIMATE AS A PREPARATORY OR TRIGGERING FACTOR IN THE GENERATION OF CATASTROPHIC LANDSLIDES IN NW ARGENTINA

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In seismically active regions the deposits of landslide-dammed lakes can be used as natural archives for past seismic activity and climatic shifts as possible trigger mechanisms for mass movements. Here we present first evidence that the temporal clustering of landslides in NW Argentina could be related to both enhanced humidity and seasonality. First, new AMS radiocarbon data from the deposits of landslide-dammed lakes in the Valles Calchaquies (S26° W66°) and the Que. del Toro (S25° W66°) show that these mass movements occurred during the Pleniglacial wet period (40 - 25 kyr BP). During this time, an intensification of the South Atlantic anticyclone and a meridional contraction of the westerly belt lead to moderately cold and relatively wet conditions as reported from other paleoclimate records. Second, detailed analysis (presented in this session) of annual-layered lacustrine strata suggest enhanced inter- and intraannual fluctuations in precipitation. These variations show mean periodicities of 3-5 and 10-13 years suggesting an influence of the El Nino/Southern Oscillation (ENSO) and Atlantic sea-surface temperature dipole. The Atlantic dipole slightly increased rainfall every 10-13 years as today. In contrast, the past ENSO influence was different from the present-day situation due to spatial shifts in ENSO-related rainfall anomalies in South America. Whereas modern rainfall is reduced during El Nino every 3-5 years, the sedimentary record shows strong evidence for dramatic rainfall events and river discharge with ENSO-type periodicites. Both increased humidity and seasonality are believed to reduce thresholds for the generation of catastrophic mass movements in NW Argentina.

Influence of the topographic amplifications under dynamic loading on the slope stability.

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The evaluation of the slopes stability under dynamic loading requires the determination of the forces of inertia. Up to now, the usual practices (pseudostatic or Newmark methods) consider an uniform distribution of these forces within the slope. In reality, forces of inertia vary locally within the slope, and result from the interferences between the incident waves and the various waves reflected, refracted and diffracted on the topography and the internal geological structures. At the surface, these interferences produce amplifications in the crest (topographical site effects), loading to easier shallow instabilities. In the case of deep-seated slides, the distribution of the forces of inertia has been studied as a function of the slope angle, the Poisson ratio and the frequencies of the incident signal. Transfert functions have been built for computing the mean accelerations to apply to the potential unstable mass.

MASS MOVEMENT AND SEISMIC HAZARDS IN CARAMANICO TERME (ITALY): SOME LINKS

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Mass movements and earthquakes represent two major geological hazards in the municipal territory of Caramanico (south-central Apennines). Most of the recent damaging landslides can be associated with periods of prolonged precipitation, represent remobilizations of older slides and exhibit low velocity. Thus their space distribution may be predicted and the temporal occurrence anticipated in reference to rainfall/groundwater monitoring. This means that, despite their considerable size and frequency (resulting in large economic losses), the rainfall-driven movements represent a low risk to humans. The slope failure hazard in relation to earthquake triggering has received little attention although the seismicity of the area is high. The intensities up to IX degree (MCS) were estimated for two historic events (1456 and 1706), whereas intensity VII-VIII was reached twice in this century. Seismic hazard evaluations indicate that intensity and PGA have 10% probability to exceed respectively the thresholds of VIII and 0.2 g in 50 years. The contemporaneous occurrence of seismic shocks and landsliding was registered on three occasions in the last four centuries (1627, 1706, 1984). These events, with local intensities ranging from VI to IX generated mass movements varying from a full-scale multiple rotational slope failure to rock/debris falls. They all occurred in the southern periphery of the town, where the debris-mantled hillslopes, underlain by overconsolidated mudstones, are capped by up to 100 m thick carbonate megabreccias. After examining the 1984 event, which produced several rockfalls (with some car-sized blocks reaching the roads and inhabited area), this paper draws attention to the rockfall hazard. Although an accurate definition of rockfall susceptible areas can be derived from a site-specific geological/geotechnical investigation, the possibility of seismic triggering complicates the prediction of the temporal occurrence. The probabilistic estimates of future events may be of limited practical value to local administrators concerned with short-term hazard reduction.

Monitoring Aseismic Slope Activity in Northern Israel: A Key to the Comprehensive Assessment of the Seismic Triggering of Landslides.

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Intense seismic activity on steep, unstable slopes, combined with abundant rainfall contribute to increase the present vulnerability of populations and infrastructures in northern Israel as well as neighboring areas. Multi-disciplinary monitoring of the non-seismic activity of unstable slopes is the first step towards the prediction of their potential co-seismic behavior. Located in an area known for its current instability and past sensitivity to earthquakes, the research site consists of a dip-slope landslide in which marls and chalks fail on bituminous shales. Monitoring rainfall, water table level fluctuation, surface and subsurface displacement and radon emission during the last 24 months has led to the quantification of the present aseismic slip rate and deformation of the landslide. Results show that the landslide, whose slip surface lies permanently below the water table, is unaffected by rainfall, and slips in pulses which could be significantly enhanced by future seismic loads.

EFFECT OF SEISMIC DISLOCATIONS ON DEVELOPMENT OF EARTHQUAKE INDUCED LANDSLIDES

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The earthquake induced landslides are one-of the types of seismic dislocations. Therefore, along with traditional methods of slope stability analysis, the study of earthquake induced landslides should include the estimate of the effect of the dynamic factor at seismic impact as well as that of the other types of seismic dislocations on the slope stability.
Studies in the Gissar village area (Tajikistan) using traditional methods to estimate the slope stability have evidenced no landslide danger. However, in the 1989 Gissar earthquake has triggered four seismically-induced landslides. The field studies the said landslides in the epicentral zone of the 1989 earthquake has demonstrated that the catastrophic slope movement had been preceded by:
- the formation of a system of seismic ruptures which have disturbed the slope mass continuity;
- liquefaction of heavily wetted loesses sensory to dynamic effect of the slope racks.
Both the physical modelling and mathematical simulation have enabled one to specify the causes and mechanism of development of seismically-induced landslides in 1989.

NH3 Earthquake risk mitigation (joint with SE)

06 Efficiency of building codes in the mitigation of the vulnerability

Convener: Petrini, V.
Co-Convener: Pujades Beneit, L.G.

NATURAL FREQUENCIES OF STRUCTURES BASED ON SIMPLIFIED IN SITU MEASUREMENTS

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The recent development of digital accelerometric instrumentation which allows a simple utilization, processing and interpretation of results, has permitted to launch a campaign to determine natural frequencies of vibrations of a large variety of different types of structures.
The measurements of ambient noise, that excites the structures, are made in different locations with a single 3-D instrument, and natural frequencies corresponding to the lowest modes of vibration, and their damping characteristics are easily identified.
Over 250 structures, among which are included buildings of different types and heights, bridges, old monuments, elevated water tanks, etc., were already tested, giving rise to a databank of information. To illustrate the interest of the data, a few examples of correlation of frequencies with geometric properties of structures are given.

EMPIRICAL DETERMINATION OF BARCELONA'S BUILDINGS NATURAL PERIODS BY USING BACKGROUND CULTURAL NOISE

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For structural design purposes, seismic codes specify formulas to estimate fundamental vibration periods of the buildings. It is important to adapt these empirical formulas to local constructive characteristics where will be applied. In Barcelona, Spain, we are performing seismic risk studies. An important input for a correct seismic risk assessment are the fundamental periods of the buildings. We have used background cultural noise as a source of excitation and we have recorded the building's response. The records have been taken in the uppermost part of the buildings. Our goal is to obtain an empirical formula linking fundamental period to some building´s characteristics like constructive typology, dimensions, number of stories, height and others. We present preliminary results obtained from the measurements performed in more than 50 buildings corresponding to the main constructive typologies of Barcelona.

PROBABILISTIC APPROACH TO BUILDING CODE CONSTRUCTION.

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Design seismic forces depend on peak ground acceleration values (PGA) and on shape of design spectrum (DS) curve dictated by Building Codes.
Underestimation of PGA or wrong evaluation of DS shapes may cause great damage of structures. These characteristics strictly depend on earthquake magnitude and distance, as well as on regional and local geological conditions. At present there is no doubt that, instead of standard DS curves, it is necessary to construct so-called *"site-specifics"* design spectra reflecting influence from different magnitude event at different distances that may occur during the construction life period.
Probabilistic seismic hazard assessments in terms of ground motion Fourier and response spectra allow us to account for both regional features of seismic waves excitation and propagation, as well as local geological conditions.
It is posible to construct Design Spectrum curves for different return period (probability of exceedence) considering ordinary, public and critical structures. In this paper the comparisons between probabilistic "region & site-specific" and standard Design Spectrum curves are shown for territories characterized by different seismicity and tectonics: the South Caucasus (Armenia, Spitak) and Turan Plate (Central Asia, Gazli).

SEISMIC RISK STUDIES IN BARCELONA, SPAIN

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A methodology to evaluate the vulnerability and seismic risk of existing buildings in an urban area, within a probabilistic scheme, is developed. It uses numerical procedures to evaluate the non-linear seismic behaviour of structures, on an optimized sampling method and probabilistic models for the description of the obtained results. This method provides occurrence probabilities for different damage levels of the structures, corresponding to a given exposure period. The problem is also analyzed from an economical point of view: annual losses and minimum earthquake insurance taxes are evaluated. Finally, the proposed method is applied to the assessment of the seismic risk of the Barcelona city, Spain, where most of the existing buildings are of unreinforced masonry or non-ductile reinforced concrete.

COMPARISON OF LOSSES BEFORE AND AFTER SEISMIC RESISTANT CODES: APPLICATION TO AN URBAN AREA

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Earthquake losses affecting a given stock of buildings in an urban area are analysed estimating the probability distribution of losses. A comparison of losses is made for two categories of buildings: (i) the ones constructed before the existence of seismic resistant building codes and (ii) the others constructed after their implementation. Probabilistic methods for evaluation of seismic losses are used taking into account both (i) the seismic hazard in the area and (ii) the seismic vulnerability and fragility of the existing building stock under consideration. The probabilistic distributions of hazard and vulnerability are convolved and weighted by spatial distribution of building inventory. Hazard estimation is based on a standard approach involving the evaluation of a seismic source model, the recurrence model and the attenuation of macroseismic intensities taking into account local soil geology. Vulnerability (mean damage ratio) for different typologies that take into account the age, type of construction and height, was modelled as a function of the seismic coefficient: five typologies before the first seismic resistant code, two after its implementation and two after the application of the most modern seismic code. For each typology, a mean damage ratio, function of seismic coefficient and macroseismic intensity was adopted. For each typology a lognormal distribution was considered to characterize the observed randomness of damage values, given the occurrence of a macroseismic intensity (fragility. The probability of losses is obtained for several reference time intervals by convolving hazard and fragility distributions. To illustrate the developed method, application to different parishes in the city of Lisbon is made. For each parish the soil condition and the distribution of building types is known. The probability distribution of losses is evaluated for individual parishess or groups of parishes taking into consideration the analysis of uncertainties of the most important parameters.

NH3 Earthquake risk mitigation (joint with SE)

07 Seismic microzonation in urban areas

Convener: Roca, A.
Co-Convener: Oliveira, C.S.

EUROSEISMOD LESSONS FOR MICROZONING STUDIES

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EUROSEISMOD, a European project gathering 16 teams from 6 countries, includes as one of its major aims the test of various routine or state-of-the art methods for site effect analysis, to be used in particular in microzonation studies. This presentation will focus on the main lessons of this project.
Based on data from a very well known test-site located in the Mygdonian graben 30 km east of Thessaloniki, as well as on a few other sites, a thorough comparison was performed on various methods proposed to infer site amplification functions from instrumental recordings: the main conclusions will be presented, especially those concerning the so-called "Nakamura's" technique.
A benchmark test was also organized to compare various modelling techniques providing numerical estimates of site effects. The results of 1D linear, 1D linear equivalent, 1D non-linear, and 2D linear models will be presented, through a comparison of their respective estimates of "engineering" parameters such as peak or rms acceleration, average horizontal spectral amplification, and duration. The effect of input parameter uncertainties was also addressed through Monte-Carlo analysis.
Finally, as the project also includes partial microzoning studies in various cities (Lower Tagus area, Barcelona, Nice, Grenoble, Liege, Benevento and Thessaloniki), several examples will be presented in order to support a proposal for a microzoning methodology.

SEISMIC HAZARD ASSESSMENT OF THE TERRITORY OF LENINAKAN (NOWGYUMRI,REPUBLIC OF ARMENIA) BY MEANS OF THE METHOD OF HIGH-FREQUENCY MICROSEISM REGISTRATION

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After the disastrous Spitak earthquake, which took place on December 7, 1988 (M=7.0), the problem of seismic microzonation of the territory of Leninakan and neighbouring settlements arose. We had set a task - to draw up a seismic hazard map for the territory of Leninakan by means of high frequency microseism registration only. Observation stations, the total number of which was about 300, were chosen proceeding from the degree of building destruction, and not from the engineering-geological conditions of the given territory. Thus, they spread all over the town and neighbouring settlements. With the purpose of evaluating the Spitak earthquake intensity in Leninakan macroseismic investigations were carried out. The degree of damage of buildings and constructions was evaluated according to MSK-64 scale. The earthquake intensity in the town was equal to 8,9,10. We composed the seismic hazard map of the territory of Leninakan by means of the method of high-frequency microseism registration and compared with the 1) map of the Spitak earthquake intensity in Leninakan drawn up according to macroseismic data; 2) map of seismic microzonation of the territory of Leninakan drawn up by means of the complex method. Now it is safe to assert that the composed by us map has justified itself, as the distinguished zones of potential seismic intensity turned out to be quite corresponding to the areas of display of analogous seismic influence intensity. In fact, reliability of the proposing method for the given territory is proved by practice.

STUDY OF SITE EFFECTS IN THE AREA OF NOCERA UMBRA (CENTRAL ITALY) DURING THE 1997 UMBRIA-MARCHE SEISMIC SEQUENCE

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The town of Nocera Umbra and neighbouring villages were severely damaged by the September 26, 1997 earthquake at 09:40 (GMT) and its largest aftershocks. In order to investigate the role played by geological conditions and topography on the level of damage, 5 seismic portable stations were used to monitor 8 sites. The studied area includes the transition zone from the Recent sedimentary filling of the Topino River valley and the outcropping unit of Umbria-Marche carbonatic sequence, which constitutes the hill where the historical centre of the town stands. More than 300 three-component recordings were selected to quantify the variation of ground motions recorded by the stations. All the analysis methods (spectral ratios using bedrock representative motions, and horizontal-to-vertical spectral ratios for both ambient noise and earthquakes) provide consistent results. In addition to the expected amplifications on soft sedimentary bodies, peculiar site effects due to topographic irregularities have been quantified.

PRELIMINARY MAP OF SOIL PREDOMINANT PERIODS IN BARCELONA BY USING MICROTREMORS

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In order to evaluate soil effects in the urban area of Barcelona, the Nakamura's technique has been used to estimate the predominant periods of soils. The measurements were performed at 200 sites, by using an accelerograph and a velocimeter. Predominant periods greater than 0.8 s are obtained in areas with consolidated sediments, named "Tricicle". Values in the range between 0.5 and 0.9 s are obtained for Llobregat deltaic deposits. On the other hand, Besòs deltaic deposits present higher periods than Llobregat delta and in some zones surrounding the outcrop rock, predominant periods between 0.10 and 0.40 s are observed. In the outcrop areas we obtained periods lower than 0.10 s. In this work, the resulting preliminary map of predominant periods is presented. In some districts, the evaluated predominant periods show a reasonably good agreement with the geological typologies and the sediment thickness; other factors may affect the results in other sites.

SEISMIC ZONATION AND ACTIVE TECTONICS OF THE URBAN AREA OF FLORENCE (ITALY).

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The city of Florence has a concentration of cultural and artistic partimony unique in the world. For this reason it has a great 'exposition'. In order to analize the seismic risk of the urban area of Florence, we have performed a multidisciplinar study. In particular, studying historical seismic sources and reelaborating local macroseismic intensity on the aid of specific algorithms, we realized an example of seismic zonation for the city of Florence relatively to the shocks of 18 May 1895 and 29 June 1919. Datas are implemented by studies at different scales of the active tectonics and active faults of the sourrondings of Florence. Furthermore, also historical evolution of the city has been examined and integrated in this study. Such an interdisciplinary approach is necessary because of the rich artistic patrimoniy of the city, where 'vulnerability' varies from zone to zone.

SEISMIC MICROZONATION IN GRENOBLE (FRANCE)

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The earthquakes in Mexico (1984) and Kobe (1993) showed that the damages observed on buildings can vary significantly in very short distances. As there is no evidence that these spatial variations are due to differences in structure resistance we think that there is a difference in the ground motion. The problem in urban area is that, most of the time, the mechanical characteristics of the soil are poorly known and that the seismic noise level is high. Then, one have to develop new procedure to determine seismic risk in urban areas.
In this aim, we ran an experiment in the town of Grenoble (France) for 10 month between april 1995 and january 1996. We installed 10 stations in 15 sites. We recorded 28 events with magnitude from 1.8 to 8 with epicentral distances from 10km to several thousands. The recording was continuous to record all the events.
We first use the spectral ratio with a reference station (CSR) to obtain the transfer function of the site at some points. Then, we used the horizontal over vertical spectral ratio calculated with noise records (HVNR) to make a map of the frequency of amplification in the whole town. Last, we used the empirical Green's function method to try to determine the effect of strong motion by using small events.
All the results are very coherent and we can propose a procedure to make a microzonation of urban areas, by using successively these methods.

COMPARATIVE STUDY OF MICROTREMOR ANALYSIS METHODS

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During a multidisciplinary microzonation pilot project in the city of Heraklion (Crete, Greece), microtremor data were collected near exploratory boreholes specifically designed for the purposes of the project, over a period of 5days, for 4 h/day at 125Hz (continuous recordings). The data were analysed with the SSR and H/V Ratio techniques, using the standard FFT (applied to long data series) and a Multi-variate Maximum Entropy (MV-MAXENT) spectral analysis method. Both techniques, implemented with both spectral analysis methods, identify the same major resonance frequency band, albeit with different amplification levels. The MV-MAXENT however is effective in handling short data lengths while yielding high resolution spectra and addressing several shortcomings of the conventional FFT (windowing, zero padding etc.). Thus, it yields competitively similar results, with only a fraction (a few minutes) of the data required by the lower resolution (FFT) method and appears to be a powerful tool for site effect investigations. Moreover, the results of both microtremor-based techniques are consistent and remarkably similar to the results of microzonation methods that require (expensive) borehole data.

SEISMIC ZONATION OF BARCELONA BASED IN PRELIMINARY SITE SPECIFIC RESPONSE SPECTRA

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The city of Barcelona is located at the Mediterranean coast, on the pediment of the Catalan Coastal Ranges. Different materials can be recognised: Paleozoic and Tertiary materials, Pleistocene terrains composed of thin consolidated sediments, and thick Holocene deposits from the Besos and Llobregat rivers.To take into account possible local effects due to the presence of sediments, seismic response of several sites in different districts have been computed. For these sites an interactive data base has been implemented with the usual geotechnical parameters obtained from drilling for building and infrastructure. After a review of published empirical correlations between geotechnical and dynamical parameters, the most adequate relation to the soil conditions of the zone has been used. An estimation of the depth of the Paleozoic basement has been obtained from an inversion of a detailed gravity survey. Future dynamic tests and geophysical prospection will contribute to improve these values.An input motion of 0.04 g has been applied according to the value considered in the Spain Seismic Code (NCSE-94). Transfer functions have been computed for all the sites using a 1D equivalent-linear code. Great amplifications rising values of 4 appear for periods less than 1.5 s. In particular the highest amplifications have been obtained at high frequencies near to 10 Hz in the districts characterised by thin deposits. Preliminary site specific response spectra characterising different zones of the city are proposed.

SITE EFFECT DETERMINATION IN NICE, FRANCE (GEMITIS PROJECT)

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Although French Riviera has a rather moderate seismicity rate, a strong seismic event is expected mainly from Genova Gulf (M=6, 30 km far from seashore). As CETE Méditerranée is based in Nice and thanks to our important geological knowledge of the city soil, it was decided to make of our own town, our first experimental field for seismic hazard assessment. Hence, as concerned with site effect, different experimental and numerical methods are used on same sites. As for many other towns, the more densely populated districts of the city lay over alluvial fillings. A first survey (1984) allows to determine regional hazard and to recognise several geotechnical areas that might have different response to earthquake. Then, during one year (1992) seismicity was recorded on 4 sites where seismic amplification could occurred. Indeed, above the main alluvial filling, spectral amplification reached 20 for low frequency as compared to rock station. Transfer function are very interesting for it shows that soil frequency and amplitude response is totally linked to alluvion depth. The present installation of 5 accelerometric stations approximately at the same sites should answer to numerous questions concerning linearity of site effect if a strong motion is recorded. Beside earthquake record, microtremor techniques were also intensively explored. Background noise stability was studied both on time and on spatial domain. It allowed to verify spectra variations during the day, but the surprising stability of horizontal to vertical spectral ratios in time. The ability of this ratio to deliver resonance frequency of soil was also demonstrate. Results were plotted as maps of frequency and relative amplification. Numerical 2D simulations are also performed over alluvial filling thanks to CESAR-LCPC code which is based on finite and boundary element method. Finally all techniques ability will be evaluated and site effect will be more described in Nice.

MICROZONATION OF THE LISBON TOWN: A THEORETICAL APPROACH

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In areas with low seismicity it is very difficult to implement microzonation techniques based on natural seismicity. Also, for urban areas, it is not easy to perform seismic experiments. Only a few methods can be easily implemented as microtremor measurements or theoretical approaches. In order to estimate the seismic behaviour of the Lisbon town, a theoretical 1D linear approach is undertaken for the entire town. Geological profiles have been performed, along the east-west direction, 500 meters spaced. These profiles were based on the existing geological map, scale 1:10 000, and complemented with new information collected from recent geological and geotechnical boreholes. The physical parameters introduced in the theoretical model were obtained from (i) specialised literature, (ii) seismic experiments and (iii) laboratory tests. These results are presented for the northeast part of the town and compared with other microzonation maps obtained using (i) microtremors measurements and (ii) impedance contrasts.

CARACAS (VENEZUELA) SITE EFFECT DETERMINATION WITH MICROTREMOR

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Caracas 1967 earthquake caused heavy damages to multi-story buildings. In 1995, 184 microtremor measurement points were performed over the city. Measurement grid was more or less dense and covered the main part of the alluvial basin as well as surrounding rock basement. For each point, horizontal record spectrum was divided by vertical one. Then the strongest value of this ratio (A) was kept as well as the frequency (Fo) where it occurs. Spatial interpolation of A and Fo were performed between all points of Palos Grandes district. A map was plotted representing a single surface where Fo is relief and A is colour gradation. Alluvion depth (H) map can be compared with this result. Damaged buildings are plotted on the same map. Fo (relief) decreases until 0.6 Hertz when alluvion depth (H) increases. Fo values fit with frequencies previously predicted from computation and with 1967 earthquake observations. The more, interpolation surfaces show that amplification (A) is very low above rock but is maximum on the south part of the basin. Now main damages of the town occurred in this part : 4 high buildings collapsed. The estimated natural frequency of these buildings were around Fo. Graphics showing H, Fo and A evolution through basin were composed. Links between all these values are noticeable. Fo is claimed to be very similar to resonance frequency of soil. As for A, it reveals to be a fairly relevant sign of damage seriousness. Microtremor technique is an economic tool and allows measurement grid as dense as desired. H/V ratio processing followed by interpolation of maximum values provides precise and useful information about expected site effect.

APLICATION OF DYNAMIC RESPONSE ANALYSIS OF BUILDINGS FOR THE SEISMIC RISK ASSESSMENT IN ALMERIA CITY.

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In general, the dynamic behavior of building structures under strong motion is depend on the structural characteristics, for example, building material, constructed age, foundation type, building story and dimension etc. and also the characteristics of input strong motion to the building. Each building has a natural period which is depend on the structural characteristics. Usually, each site where some buildings were constructed has a predominant period which is depend on the uppermost soil condition, for example, the stiffness and depth of uppermost soil layer, respectively. Even if the uppermost soil condition is not so soft, basically, the relationship between the natural period of building and the predominant period of surrounding uppermost soil condition is very important to evaluate the earthquake damage for the buildings. So we have performed to estimate the natural period of existing 23 buildings which have the stories from 4 to 10 in Almeria City using microtremor observations at the top of buildings. These buildings have different characteristics respectively, but, in this research, we are thinking that one very important index of building characteristics is the building story. The relationship between the building stories and the natural periods is very linear and clear. The result shows : T=0.048N in lateral movement and T=0.047N in torsional movement, where T is the natural period in sec., and N is the building story from 4 to 10. After we get these results, we have tried to calculate the dynamic behavior of buildings using the response analysis of 1-DOFS Model, considering the different uppermost soil conditions. We would like to show the result of response analysis in order to assess the seismic risk in Almeria City.

GRAVITY ANOMALY MAP OF BARCELONA AS A TOOL FOR DETERMINING THE STRUCTURAL FRAMEWORK AND DEPTH TO BASEMENT IN RELATION TO SEISMIC MICROZONATION OF AN URBAN AREA

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Barcelona is situated over colluvial and alluvial deposits between Llobregat and Besos River deltas and these materials overlay Pliocene marls and the Hercinian basement. In the scope of a project for the evaluation of the seismic hazard of the city of Barcelona, sponsored by the city council, several geological and geophysical studies have been carried out with the aim to evaluate local conditions that would modify earthquake response.

A Bouguer gravity anomaly map of Barcelona was produced by the compilation of 935 gravity stations, with coverage throughout the city and surroundings of 1 station/km2. New gravity stations are being surveyed over a high precision network to perform a 200 m grid interval. From the inverse solution of the residual gravity anomaly, depth to basement and the structural framework have been determined, in spite of the lack of subsoil control data. This information has been useful for assessing the earthquake hazard at local scale.

THE INFLUENCE OF THE EXPERTS OPINION IN MICROZONATION STUDIES

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Recently a qualitative microzonation study has been completed for the city of Basel. The study includes the mapping of the geological and geotechnical soil conditions which are known from over 2700 shallow wells. This comprises also detailed lithological descriptions of the cores, thicknesses of the strata, groundwater data, and SPT measurements. Measurements and interpretations of ambient noise and their comparison with the local geological information lead to a characterization of the different soil types. The microzonation is performed by means of a qualitative rating scheme that takes into account the influence of seven characteristic parameters of the local soils which can be the cause of amplification of ground motion during earthquakes. Four parameters account for the influence of the Quaternary gravels. These are the consolidation of the gravels, the type of the Quaternary sediments, the thickness and the lateral variations of the thickness. A fifth parameter considers the potential of liquefaction. Finally two parameters account for the influence of the Prequaternary sediments and of the Rhinegraben master fault. The original weighting scheme has then been analysed by four experts, and each expert proposed a new scheme for the microzonation, which is also based on the seven parameters. The different rating schemes and their effects on the microzonation are discussed in this contribution. Even if there are large differences in the weighting of some of the parameters, the overall features of the different microzonation maps remain stable.

EVALUATION OF SITE EFFECTS IN VOLVI BASIN (GREECE) FROM EXPERIMENTAL DATA AND MODELING

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The results of amplification estimates due to site effects, as obtained from observed data and theoretical modeling, are compared. The data come from the Volvi basin, a test site located in Northern Greece near the city of Thessaloniki (EUROSEISTEST). We calculate the synthetic seismograms (SH and P-SV waves) for a 2D section of the target area between the Profitis and Stivos villages, where the recording stations are located. The hybrid technique employed for these computations couples the modal summation and the finite difference methods. Both in time and in frequency domain the agreement between our simulations and the observed data is satisfactory. The few observed discrepancies are very probably connected to the still limited knowledge and estimates of the parameters necessary to define the source, the propagation path and the 2D model in the hybrid technique.

SEISMIC MICROZONATION IN PREADRIATIC URBAN AREAS OF ALBANIA

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Based on seismic microzoning studies carried out, during last 15 years, in Preadriatic area of Albania, for many important inhabitated centers and cities(as Vlora, Durres, Shkodra, Fieri and Tirana city) , a comparison of different approaches with experience gained by past and recent earthquakes is shown. Some special case studies are of interest, taking into account the occurrence of recent earthquakes (Tirana & Shkodra case studies) and those of the past(Durres , Fieri & Vlora case studies).On the other hand based on seismic hazard maps compiled at local scale, the implemetation of outputs of seismic microzoning studies in physical and urban planning of some important towns (as Vlora, Durres, Shkodra, Fieri) and Tirana city and for the improvement of Albanian seismic building code, are presented..

EXPERIMENTAL SITE EFFECT EVALUATION IN URBAN AREAS OF THE UMBRIA AND MARCHE REGIONS (ITALY)

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After the 26 september 1997 Central Italy earthquake ($M_L = 5.9$) the Italian Civil Protection Department issued a seismic microzonation project. Its goal is to perform detailed investigations on some of the heavily damaged localities (Fabriano, Nocera Umbra and Sellano) with the aim to provide guidelines for urban planning and building retrofit.
In this framework a special task group devoted to site effect evaluation (Umbria Marche Site Effect Group) has been set up. This group installed three temporary seismic arrays with 54 sites monitored in the urban areas of the above mentioned localities, recording at least 20 events with magnitude up to 4.4. The preliminary results presented concern empirical transfer function evaluations based on spectral ratio technique. Reference site and single site approaches were used both for earthquake and noise recordings.

2-D STRONG MOTION SIMULATION FOR MICROZONING OF BUCHAREST

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The strong intermediate-depth Vrancea (Romania) earthquakes represent the main seismic source that has to be taken into account for microzonation purposes of Bucharest that, due to its poor soil conditions, could suffer serious damage because of the severe local site amplification. The realistic modeling of ground motion is made computing the seismic input for the target area of Bucharest considering a 2-D cross-section profile by means of a sophisticated hybrid technique, that combines modal summation and finite difference scheme. As seismic source we consider two strong Vrancea quakes (August 30, 1986, M_w=7.1, and May 30,1990, M_w=6.9). The simulated signals are analyzed against the few available instrumental records. The main features of the local response simulated under the mentioned conditions are similar to the observed ones. We see how this technique can lead to a proposed microzonation of the city of Bucharest. For the complete microzonation of Bucharest the computation will be extended to a set of cross sections that cover the whole area of the town and to a set of source parameters of strong Vrancea quakes.

REALISTIC MODELLING OF SEISMIC INPUT IN URBAN AREAS: A UNESCO/IGCP PROJECT

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The accurate study of geological and site effects on seismic ground motion and their realistic modelling addresses the problem of pre-disaster orientation: hazard prediction, risk assessment, and hazard mapping. The major scientific problem is to handle realistic models on a very detailed level. We can reduce loss of life and property damage by highly detailed, specific prediction of seismic ground motion. To map seismic ground motion we do not have to wait for earthquakes to occur in likely focal regions and then to measure ground motion with an extremely dense set of recording instruments; instead we can compute immediately these seismograms from theoretical considerations. This database can be updated continuously incoming new experimental data. The plan of the UNESCO/IGCP Project "Seismic Ground Motion in Large Urban Areas" includes a broad spectrum of seismic hazard levels that require different administrative, politcal, scientific efforts to reach a satisfactory preparedness (Antananarivo, Bangalore, Beijing, Bucharest, Budapest, Catania, Delhi, Kathmandu, Ljubljana, Mexicali, Mexico City, Naples, Rome, Santiago de Chile, Santiago de Cuba, Silistra, Sofia, Thessaloniki, Tijuana, and Zagreb). The project, the methodology followed for the simulation of ground motion and the results obtained in several cities are illustrated, including comparisons between the outcome of simple and very sophysticated approaches.

DETAILED SEISMIC MICROZONING OF ALMERIA CITY USING GEOTECHNICAL INFORMATION AND MICROTREMOR OBSERVATION

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The importance of seismic microzoning and seismic risk assessment is increasing in earthquake prone area of the world for earthquake damage reduction. We have engaged in detailed research on seismic microzoning and seismic risk assessment in Almeria City since 1996. This detailed research is composed of several different works as followws. (1) Geomorphological Investigation : A landform classification map is developed by analysing aerial photos and large scale topographic maps. Since each landform is composed of different materials, it represents the uppermost part of the soils. Some geologic cross-sections are compiled from bore hole records in order to examine the deeper part of the soils.(2) S Wave Velocity Prospecting Test : S wave velocity prospecting tests are experimented at several sites. These results are usefull for understanding the uppermost soil characteristics and are used for soil classification. (3) Microtremor Observation : Microtremore observations are densely carried out in the research area. These result will be used in the evaluation of dynamical ground properties, for example, predominant period and amplification factor and will be used in seismic microzoning. (4) Seismic Strong Motion Observation : Seismic strong motion observation sites are located at four sites in the research area where are different soil condition, especially, one of them is located at hard rock site. These strong motion records are compared with each other to recognize the difference of ground shaking characteristics. (5) Integration for Seismic Microzoning : Detailed seismic microzoning is carried out by compiling the results of (1) - (4). As a result, the research area is divided into several districts which have identical characteristics of dynamical soil properties, respectively.

SITE EFFECTS IN THE CITY OF THESSALONIKI (GREECE): ESTIMATES FROM DATA AND MODELLING

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In the present study the site effects in the city of Thessaloniki (Greece) are estimated using both an experimental and theoretical approach. The experimental techniques are applied to a set of observed accelerograms. The technique of Standard Spectral Ratio (*SSR*) is applied to a reference station located on rock, while the *H/V* Spectral Ratio technique is used both with earthquake records (entire length including P & S waves) and with recorded noise. The results from all previous methods are compared in terms of predominant frequencies and amplification levels. The fundamental frequency is identified by all methods, though the average amplification level is generally underestimated when the *H/V* spectral ratio techniques are used.
For the numerical approach, we construct complete strong motion synthetics using the modal summation method, up to frequencies of 10 Hz, for the *P-SV* waves. As input, four point sources are used, located at different distances and azimuths from the stations. Ratios of response spectra of the local 1-D over the regional 1-D seismograms are calculated. The mean spectral amplifications obtained, are compared with the experimental ones.

The Earthquake Sequence of Events During the June-October 1997 Crise in the Azores Observed under Different Soil Conditions

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Abstract

An earthquake sequence of events occurred in the Azores since 27 June 1997 and lasted until mid October. The main events were recorded in a few strong motion instruments recently implanted in the region.
During the three and half months of activity 64 earthquakes with epicenters in the ocean near the Banco D. Joao de Castro, between the islands of Sao Miguel and Terceira, were recorded in 3 to 5 stations in those two islands, producing 99 records with 3 components. Maximum local magnitude was of the order of 5.5 and epicentral distances, to the stations, range from 30 to 120 km. Peak ground accelerations range from 0.5 mg to 50 mg, depending on the epicentral distances and on the soil type. Soil properties are behind the large differences (twice in amplitude) between ground motion recorded at a location within an old crater and another at its borders, two hundred meters away.
The present paper presents the records obtained in the crise and tries to explain the most important features observed at the different locations.

MICROTREMOR ANALYSIS TO CHARACTERIZE SEISMIC WAVE ATTENUATION IN THE CITY OF BARCELONA

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Microtremors are generated by the presence of short period seismic noise, and they consist of a mixture of surface and body waves. The surface sources of this ambient noise are of different origins: traffic, factories, cultural activity, etc. Microtremor recordings usually present an average amplitude that is constant with time, but sometimes interferences caused by specific easy to find sources located near the recording instrument are observed. These small events are produced, as an example, by the passing of a person or vehicle, and we will try to use them in order to characterize the capability of the medium to attenuate seismic energy. In this study, the parts of the records that present high amplitudes are analyzed, and the amplitude decays are characterized by a quality factor Q. Preliminary results for different zones of the city of Barcelona are presented. They show the ability of this method to characterize the attenuation of the different soil typologies.

ESTIMATION OF THE SYSTEM FUNCTION OF SOILS USING MICRO-TREMORS

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The use of microtremors to characterize soils using the methodology proposed by Nakamura in 1989, has been a topic of microzonation studies for many years, due to its rapidity and low cost. This method allows to obtain accurately the resonance frequency of a given sedimentary layer, but it fails to predict the amplification at the resonance frequency. In this study an improvement of the Nakamura's spectral ratio (horizontal versus vertical components) is proposed so that the obtention of the predominant periods and amplifications using microtremor measurements at the surface is allowed. Using the 3 component recordings of microtremors, it is considered that the vertical component represents the vertical tremor at the substrate, except for the presence of uncorrelated noise (W_v). The horizontal components constitute a complex signal that (except for uncorrelated noise W_x) represent the horizontal tremor obtained by filtering the movement at the substrate with the soil's system transference function H. This system function H is then estimated by minimizing the uncorrelated noises W_v and W_x. This methodology is applied to microtremor measurements in the urban area of Barcelona.

NH4 Volcanic hazards: field studies, instrumentation and observation networks (joint with SE)

Convener: Kilburn, C.
Co-Convener: Vougioukalakis, G.

GPS AN DIGITAL PHOTOGRAMMETRY FOR MONITORING GROUND DEFORMATIONS ON A VOLCANIC AREA.

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In September 1996 an airborne GPS-photogrammetric project was performed over the Vulcano island (Aeolian Island Arc) in order to experiment a fast and accurate procedure for an aerial photography mapping application for ground deformation monitoring. The use of GPS observations for establishing the position of the photo centers at the instant of exposure, reduces the number of required ground control points; the processing of the images in digital form, from image scanning to the Digital Terrain Model generation, allows for time reduction when automatic procedures can be successfully applied. The data collected during the experiment, that is images at 1:5000 and 1:10000 scale, were digitized at a resolution of 1000 dpi, and analyzed using the Helawa system which adopts a correlation algorithm working at subpixel level, with a resulting ground resolution of about 5 cm. GPS kinematic camera positions were obtained installing two receivers on the aircraft and three reference stations on the ground which continuously operated during the flight mission. GPS kinematic solutions were obtained using both commercial and scientific software's with OFT capabilities. The experiment allowed to define the geometry of the calderic structure with an accuracy at the decimeter level, confirming that the aerial photogrammetry, even if generally less precise than geodetic surveys, gives the possibility of defining with higt spatial resolution the strong deformations process of volcanic area.

GPS MEASUREMENTS IN THE NEAPOLITAN VOLCANIC AREA

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Among the institutional activities of the Osservatorio Vesuviano, there is the surveillance of the Neapolitan volcanic area (Mt. Vesuvius, Phlegrean Fields and Ischia island) which is carried out also through the study of ground deformations. In the last two years, a GPS network in the above mentioned area was established. In Mt. Vesuvius area a GPS test was carried out in order to verify the possibility of the installation of a network of GPS permanent stations. A quality control of the acquired data was made with the QC software by UNAVCO, then the processing phase was carried out using two different programs (BERNESE and GEOTRACER) for a cross control of the results. In the Island of Ischia three different techniques (static, fast-static and real-time-kinematic) have been used to get a first set of coordinates and to perform a comparison between the three metodologies. GPS data of the Phlegrean Fields are still in processing. The results for Mt. Vesuvius area and the Ischia island are presented and discussed.

TSUNAMIS GENERATED BY VOLCANIC EXPLOSIONS: DATA FROM 1996 ERUPTION IN KARYMSKOYE LAKE (KAMCHATKA, RUSSIA)

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The 1996 subaquatic explosive eruption in Karymskoye lake (4 km across, maximal depth 70 m) generated multiple tsunamis. We document the tsunami effects and runup. These data enable determination of a law of attenuation of runup (wave) height for "explosive" tsunamis, which is compared with theoretical modelling. For the proximal zone, to radial distances (r) up to 1.3 km, the runup height (R) shows rapid attenuation (from >30m to 8 m) with distance as $\log R = -0.56 \log[r] + 5.8$. For the distal zone, $r > 1.3$ km, R decays more slowly (from 8m to 3m) as $\log R = -1.98 \log[r] + 16.3$. Rapid decay in proximal zone suggests that in the near field of the explosion the tsunami propagate as a collapsing wave with discontinuous change in height. The break-in-slope of the runup plot at 1.3 km suggests that the tsunami propagate further as a decaying one-dimensional wave in a channel of approximately constant width.

TSUNAMIS GENERATED BY LARGE SCALE FAILURES OF COASTAL VOLCANOES - EXAMPLES FROM KURILE-KAMCHATKA REGION, RUSSIA

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Our investigation of Harimkotan volcano (Kurile islands) has shown that tsunami up to 20 m high, witnessed during its 1933 eruption (Miyatake, 1934), was generated by volcanic debris avalanche which entered Pacific Ocean. Subaerial part of the avalanche deposit forms a broad hummocky fan (max thickness 10-20m; length 7 km; area 20 km^2; volume 0.4 km^3). The avalanche smashed the ocean along 8 km of coastal line. It was formed as a result of large scale failure of the volcanic edifice 1213 m high. Multiple (>4) prehistoric debris avalanche deposits spreading offshore were discovered on the island. That is the evidence that tsunamigenic failures, similar with the 1933 event, repeatedly occurred in the history of the volcano. Youngest of them were 1100 and 2000 C^{14} years ago. Failure of Avachinsky volcano (Kamchatka peninsula) in the end of Pleistocene produced debris avalanche with the volume approximately 10 km^3. The avalanche travelled the distance more than 24 km and entered Avachinsky Bay along the shore line 5 km long. Thickness of the avalanche deposit in modern sea cliff is more than 50 m. Generation of strong tsunami was inevitable in that situation.

SUBSURFACE MASS REDISTRIBUTION DETECTED BY MICRO-GRAVITY STUDIES AT MT ETNA, 1995-96

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Gravity changes observed by regular migrogravity surveys indicate that significant magma movement continued within Etna's central feeding system between 1994 and 1996, a period including the 1995-96 explosive activity at the summit. Early magmatic changes were detected along Etna's Summit Profile when, between September 1994 and October 1995, some 2 x 10^{10} kg of magma were intruded beneath the summit region at about 1000 m a.s.l.. The positive anomaly due to this intrusion disappeared during the following nine months (coinciding with violent strmbolian activity at the summit), while a new positive anomaly (of about 2 x 10^{10} kg) was detected below about 1000 m a.s.l. and within the 1989 fracture system. None of the anomalies was accompanied by significant changes in ground elevation or seismicity, suggesting a passive mechanism of injection. At the same time, measurements along the E-W Profile detected some 1.5 x 10^{11} kg of magma accumulating 2-3 km below sea level. Magma thus appears to be infiltrating the 1989 fracture system, which fed major flank eruptions in 1989 and 1991-93. The 1989 fracture system must therefore be considered active and, hence, a favoured site for flank eruptions in the near future.

CONTINUOUS GRAVITY RECORD AT MOUNT VESUVIUS: A TOOL TO MONITOR ITS DYNAMICS

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High precision relative and absolute gravity measurements are periodically carried out on Mt. Vesuvius (Southern Italy) to monitor gravity changes associated with its dynamics. Since 1987, a permanent recording gravity station also operates on the volcano aimed at a continuous record of the "non-tidal" gravity changes.
Here we focus on the results of more than 3 years of gravity records starting from 1994. Tidal analyses have been carried out on the data-set using several methodologies. The ocean and atmospheric effects have been taken into account for the computation of the gravity residuals.
The time behaviour of the main tidal parameters and of the gravity residuals have been compared with some features of the vesuvian dynamics, mainly with the temporal gravity changes detected by absolute and relative gravimetry.

PRECURCURSORS TO THE PLINIAN ERUPTIONS OF THERA (1628 BC) AND VESUVIUS (79 AD): DATA FROM ARCHAEOLOGICAL SITES.

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Stratigraphic evidence from the Bronze Age settlement of Akrotiri (Santorini, Greece) and the Roman towns of Pompeii and Herculaneum (Vesuvius, Italy) has been used to investigate the scale of pre-eruptive phenomena before the plinian eruptions of Thera in 1628 BC and of Vesuvius in 79 AD. Both eruptions were characterized by precursory seismic activity, but with very different magnitudes and impact on local populations. The Akrotiri settlement was badly damaged by strong earthquake(s), forcing an early evacuation of the island and destroying Akrotiri before the eruption began, as shown by the fallout pumice bed which mantles the ruins and has preserved the state of destruction. No clear evidence exists of intense, destructive seismic activity immediately before the AD 79 eruption of Vesuvius, and only low-magnitude shaking has been recorded. Indeed, weak seismicity would account for local populations being caught unawares by the eruption. None of the deposits at either volcano show evidence of major precursory volcanic phenomena (magmatic or phreatic). In both cases, the main eruption was preceded by low-energy phreatomagmatic pulses, strongly suggesting that pre-eruptive behaviour was conditioned by diffuse hydrothermal activity.

MICROGRAVITY MONITORING OF PITON DE LA FOURNAISE VOLCANO (LA RÉUNION)

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In order to achieve a greater accuracy in the gravity monitoring of Piton de la Fournaise volcano, we carried out four microgravity surveys from 1993 to 1997 to complement the existing network. The complete network now contains more than 100 stations distributed on the volcano. A reference base line was established to check the calibration of the meters during each survey. The gravity and geodetic measurements are now simultaneously performed using several high resolution Scintrex CG-3M gravity meters and Ashtech GPS receivers for kinematic positionning. An interactive computer program including precise earth tide model and adjustment procedure of gravity observations has been especially designed to process Scintrex CG-3M gravity data. The final accuracy obtained on gravity values on this repetition network is estimated to be in order of 15 to 20 μGal. To detect possible shorter term variations associated with the volcanic activity, we have also set up two CG-3M meters located at different sites of the volcano. Meteorological recordings are also performed simultaneously in order to remove external pressure and temperature effects from the gravity signal. We present here the microgravity data acquisition and processing. We discuss our first results and their implications for the understanding of the magmatic system of Piton de la Fournaise volcano.

KINEMATICS AND MECHANICS OF LATERAL COLLAPSES ON OCEANIC ISLAND VOLCANOES, AND THEIR EFFICIENCY AS TSUNAMI SOURCES

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Giant lateral collapses and debris avalanches on the flanks of oceanic island volcanoes, with volumes of 100 to 2000 cubic kilometres, have been linked to the formation of giant tsunami, most notably by Moore et al. who have identified deposits from such tsunami in the Hawaiian archipelago. Similar deposits have recently been found by us on volcanic islands in the Atlantic ocean. If deposits of this type are generated by lateral collapses, then these must be more efficient tsunami sources than continental slope sediment failures of similar volume. Our studies of large-volume debris avalanche deposits on Gran Canaria and of an aborted rift flank collapse on the island of El Hierro indicate that flank collapses on these islands begin by rapid sliding of a single rigid mass. Motion breaks the mass into large blocks whose relative movements on intervening faults are small compared to the dimensions of the blocks and to the bulk displacement of the failing mass (~ 100 m as compared to at least 5 km in the case of a displaced block terrane on Gran Canaria). We therefore consider that models of tsunami generation by sliding blocks (which indicate highly efficient tsunami generation) are more closely applicable to oceanic island lateral collapses than models of tsunami generation by sediment flows.

GEOMAGNETIC PREDICTION OF VOLCANIC ERUPTIONS

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The structural heterogeneity and the dynamics of the plumbing system of each volcanic edifice can strongly condition typology and characteristics of the precursory signals of eruptions. Traditionally, ground deformations and seismic activity studies are used to detect such precursory signals. However, both methods point out local phenomena such as a rupture along a fault plane or local deformations along a fissure system. These techniques can be usefully supported, for monitoring volcanic activity, by the magnetic method that integrates the effect of a phenomenon over a large volume. Variations of the magnetic properties of the rocks generate a wide variety of magnetic signals that can also appear a long time before eruption and are generated by different mechanisms. In particular, a meaningful change of magnetic field is expected in the case of an eruption of a basaltic volcano as Mt. Etna containing a large amount of magnetic minerals, which modify their magnetization when subjected to temperature variations or when submitted to a mechanical stress. In order to evaluate the suitability of magnetic surveillance to volcano prediction on Etna, we analyzed two historic series of magnetic data recorded there: i) during the 1981 eruption and ii) immediately after 1989 eruption. Moreover, we examined time series associated with the intense explosive activity of Etna in 1995 summer provided by the present permanent magnetic network which was set up between 1994 and 1995.

THE SOURCE PARADIGM OF THE VOLUMINOUS IGNIMBRITES OF THE SIERRA MADRE OCCIDENTAL, MEXICO.

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The Sierra Madre Occidental (SMO) covers at least 360,000 km^2 in Northern Mexico and is the largest continuous ignimbrite province in the world. Its magmatic evolution can be divided into the Lower Volcanic Complex (LVC) and the Upper Volcanic Supergroup (UVS). The LVC consists of intermediate-silicic volcanic and plutonic rocks of Upper Cretaceous-mid Tertiary age, while the UVS is essentially an ignimbrite plateau of Eocene-early Miocene age. A conservative estimate of the physical volume of the SMO ignimbrites is about 360,000 km^3 (1,200x300x1 km). However, only a few calderas have been identified in the province, either because additional calderas have been covered by younger ignimbrite sheets, or because fissures, with the NNW regional orientation of the Basin and Range faults, served as conduits for much of the ignimbrite. These fissures are several kilometers long and are represented by a combination of (1) rhyolite dikes emplaced along extensional features, such as the flexure zone in the shoulder of half-grabens, and (2) co-ignimbrite lithic-lag breccias with a linear alignment several km long and also oriented NNW. Both types of source may have occurred in the SMO, with fissures predominating in areas more affected by extension, and calderas occurring in relatively less extended areas.

NEW GRAVITY SENSORS AS PROBES OF VOLCANIC ACTIVITY

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A new and smaller absolute gravimeter and a new gravity gradient sensor will be described together with their relevance to volcanic monitoring. Gravity changes have proven useful in the monitoring of volcanic activity. The demands of portability in a difficult and remote environment have here-to-fore caused relative gravimeters to be the major investigative tool. Instrumental drifts and tares however require closure of measurement loops with these instruments in order to approach useful precisions in the 10-20 μ gal range. A new and smaller absolute instrument which is under development at JILA will be described which is intended to ameliorate some of these problems. In addition a low cost (5-10K) and truly field-compatible (i.e. one person portable; weight < 17 kgm) gradiometer intended for permanent instillation at sites near regions of volcanic activity will be described. Such an instrument would provide continuous registration of mass motions at the "equivalent" 10-20 μ gal level of sensitivity. Used separately or in combination these under-development gravity sensing instruments should help us better to "see", and thus understand, the details of magma motions.

SELF-POTENTIAL STUDIES OF HYDROTHERMAL SYSTEMS AND STRUCTURE ON MISTI AND UBINAS VOLCANOES, S. PERU

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Misti stratovolcano (16:18°S, 71:24°W, 5822 m), 14 km NE of Arequipa (pop. c. 900,000) contains two concentric summit craters, in the younger of which is a small lava dome with fumarolic activity. A self-potential (SP) investigation over 100 km^2, combining long radial profiles, has revealed two kinds of zones when SP values are plotted against altitude. The first shows a linear, inverse correlation between SP and elevation, a trend expected from standard hydrogeological models. The second instead shows a direct correlation, suggesting a hydrothermal system. The boundary between hydrological and hydrothermal zones is circular, about 6 km across, and correlates well with the edge of an old caldera, whose walls might limit the lateral extent of a convective system of rising gas. Ubinas stratovolcano (16:22 °S, 70:54 °W, 5672 m) is truncated by a summit crater, 1.2 km across, which partly overlies another deep crater (500 m across, 200 m deep) whose fumarolic activity has become more vigorous since December 1995. Detailed SP and thermal infra-red investigations (to 15 cm depth), involving more than 5700 measurements inside the large summit crater, do not show any anomaly, perhaps due to the absence of an extensive fracture system. Such a closed-system interpretation is consistent with the leakage of pressurised gas that can easily be heard more than 1 km distant.

GEODETIC MONITORING OF DYKE EMPLACEMENT, SLOPE INSTABILITY, AND FAULT CREEP AT MOUNT ETNA

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Dyke-induced rifting events have occurred on the east flank of Etna four times over the past fifteen years, in 1983, 1985, 1989, and 1991. Regular surveying of a geodetic network, established on the upper flanks of the volcano in 1981, has revealed lateral displacements ~ 1m associated with each event. This matches the average widths of prehistoric dykes exposed in the walls of the Valle del Bove sector collapse structure. The largest cumulative movements are observed adjacent to the back wall of the Valle del Bove, where the 1km high cliff has been displaced eastwards by over 5m since 1983. Strains accumulating in the upper levels of the volcano appear to be released over time by aseismic creep and periodic earthquakes on faults bounding, and enclosed within, the mobile eastern sector of the volcano, which is being displaced seawards at centimetric annual rates. Observed deformation was minimal during the four years following the end of the major effusive eruption of 1991-93. However, extension between 1996 and 1997 argues for the emplacement of fresh magma into the same fracture system which fed the 1991-93 eruption. Results from contemporaneous microgravity surveys support this interpretation, and highlight the importance of integrated, multiparameter monitoring to eruption forecasting.

CROSS-CORRELATION BETWEEN VOLCANIC TREMOR AND SO_2 FLUX DATA FROM MT. ETNA VOLCANO

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Significant hints on the current eruptive state of a volcano may be inferred from both geophysical and geochemical monitoring. In this work volcanic tremor and sulphur dioxide emissions, measured during the period October 1987 - July 1995 on Mt. Etna, were analysed. The aim is to give a quantitative and systematic description of the correlation between the two data series and to evaluate a possible association to the volcanic activity of Etna. On this purpose a cross-correlation analysis was performed. The results indicate that volcanic tremor and SO_2 time series have a similar increase in correspondence of the largest eruptions. Hence, in the strong eruptive episodes, volcanic tremor and SO_2 flux seem to originate from a common physical mechanism related to magma dynamics.

PYROCLASTIC FLOW HAZARD IN THE MAXIMUM EXPECTED EVENT AT CAMPI FLEGREI (ITALY)

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Numerical simulations of pyroclastic flows generated by the collapse of an eruptive column in the maximum expected event at Campi Flegrei (Italy) are performed in order to estimate the associated hazard. A multiphase and multicomponent model based on transport theory is adopted. The solid phase consists of particles of two granulometric sizes and densities, whereas the gas phase is composed by the magmatic gas (H_2O) and the atmospheric air. The simulated event is assumed similar in intensity to the "Agnano Monte Spina" ($\approx$ 4Ka) and the "Pomici Principali" ($\approx$ 10Ka) eruptions. A parametric study is performed to analyze the effect of the initial water content, vent diameter, and topographic profiles on the flow propagation, and to define the conditions at the vent causing the pyroclastic flows to overcome the topographic reliefs (Posillipo's Hill) located between the Phlegraean Fields and the city of Neaples. Results show the important role played by the topographic relief in reducing the pyroclastic flow hazard. Only for particular input conditions and vent location the pyroclastic flow may overcome the topographic relief, reaching the neighbours of Neaples.

RETROSPECTIVE IDENTIFICATION OF PHENOMENA CORRELATED WITH VOLCANIC ERUPTIONS

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One of the main tools in phenomenological studies is the identification of correlations among different processes. This is essentially effected in retrospective with the specific aim of finding a positive result, and that leads to a parameter optimization which introduces a bias, so far essentially disregarded, in the significance level of the results. If the correlation can be validated in a forward study in which parameters are kept fixed, such a bias is irrelevant. Unfortunately, forward studies are mostly impractical in Geophysics since they would require to wait for a very long time. Unbiased estimates can be obtained in retrospective if each of the optimal choices is properly identified and accounted for. An application of this correction to the apparent seismic "precursors" of Mount Etna volcano flank eruptions shows that these are most likely to be artifacts of the retrospective optimization.

NUMERICAL SIMULATION OF A POTENTIAL DEBRIS AVALANCHE IN MONTSERRAT, LESSER ANTILLES

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The Soufriere Hill's volcano in Montserrat, Lesser Antilles, has been erupted since July 1995. The extrusion of lava lead to the formation of a new dome in the active English's Crater. The evolution of volcano's activity could lead to dome collapse generating a tsunami. Preliminary simulations, assimilating the debris avalanche to a fluid flowing in a U shape valley, lead to waves ranging from 1 to 2 meters reaching Guadeloupe island, situated 50 km at the Sud-Est. We have developed here a numerical debris avalanche flow model, based on more physical assumptions. The debris avalanche is described by a Coulomb type friction law. This model solves vertically integrated long wave equations. A sliding mass of about 100 millions of cubic meters is flowing to the East towards the sea. The simulation is done by using a MNT of the Tar River Valley, Montserrat. We show that the topography and the mechanical behaviour change significantly the velocity and the front height of the mass reaching the sea. The height of the simulated tsunami is reduced.

THE VOLCANOSEISMIC CRISIS OF 1996-1997 IN NISYROS, SE AEGEAN SEA, GREECE

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After a repose time of several years an intense, shallow seismic activity started by the end of 1995 in the volcanic region of Nisyros Island. By the end of October 1997 hundreds of shocks were recorded, the largest one being that of 27 August 1996 with M_L=5.3. The activity is highly clustered in space and time while the b-value of the magnitude-frequency relation was found equal to 1.67. Similar b-values were determined from the Nisyros seismicity of 1911-1980 and from an 1997 data set of microearthquakes. These seismicity properties seem to be a characteristic of the region rather than precursor of a forthcoming eruption and make Nisyros similar to other large calderas of the Earth where the episodic unrest with local swarm-like earthquake sequences separated by months or years is a typical pattern that do not culminate in a volcanic eruption.

DEVELOPMENT OF A MIXED-MODE GPS GEODETIC NETWORK AT SOUFRIERE HILLS VOLCANO, MONTSERRAT

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We have developed and maintained a mixed-mode GPS geodetic network for monitoring Soufriere Hills volcano. Network evolution may be divided into four phases: (1) network establishment with L1-carrier phase observationsduring August 1995; (2) daily L1/L2 observations between October 7, 1995 and December 29, 1995; (3) network densification to 14 sites with nearly daily L1/L2-carrier phaseobservations between May 14, 1996 and August 8, 1996; (4) installation of two continuous GPS sites in July 1996 and intermittent reoccupation of all network sites from September 1996 to present. Initial GPS observations were made in August 1995 using two Trimble GeoExplorer 6-channel, L1 carrier phase receivers with internal antennas. Dual-frequency GPS observations began on October 7, 1995 using three 9-channel Trimble 4000SSE receivers with Trimble 4000SSE/SST L1/L2 antennas with flat ground planes. Dorn-Margolin chokering antennas were substituted in May 1996. The three receivers were moved among the 6 sites (one held fixed), and data were collected using a 30s sync rate for between 16 to 24 hr per UTC day. Continous GPS data from Montserrat is compared with other tropical sites to clarify possible long-term trends and to identify periodic volcanic behavior. A phase dispersion minimization (PDM) algorithm is used to analyze the time series in addition to the standard Fourier Transform techniques. Advantages of PDM are: (1) no waveform is assumed; and (2) uneven sampling is more easily handled.

GROUND DEFORMATION MONITORING AT SOMMA-VESUVIUS AND CAMPANIAN VOLCANIC AREA (ITALY).

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We present an integrated ground deformation network aimed to monitor volcano-tectonic movements in the area of Neapolitan volcanism. It covers an area of more than 10000 km2, including the volcanic centers of Somma-Vesuvius, Campi Flegrei caldera and Ischia island. It includes levelling and EDM networks, as well as GPS periodic and continuous measurements. The scope of the network is twice: monitoring ground deformations in volcanic areas, and studying the complex tectonics of the Campania Plane, a graben-like structure in which all the Neapolitan volcanism is concentrated, as related to the tectonics of Southern Apennines. The monitoring network consists of a larger scale, levelling EDM and GPS network covering the whole Campania Plane, connected to the stable areas of Apennines, and smaller scale networks aimed to accurately monitoring the Somma-Vesuvius volcano, the most dangerous over the World because of its high urban development. The Somma Vesuvius is monitored by an over 200 km long levelling network, by periodic EDM and GPS measurements and by a small network of continuously monitoring GPS instruments. The main features of the networks, as related to the monitoring capability, are presented, as well as the most recent measurement results. The performance and efficiency of the networks for the interpretation of data in terms of volcanic and tectonic models are also discussed.

AN INTEGRATED MONITORING PROJECT FOR THE MODELLING OF MT. MELBOURNE VOLCANO INTERNAL DYNAMICS (ANTARCTICA)

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At present, volcanic activity of Mt. Melbourne consists of low temperature fumaroles and ground heating, but studies on pyroclastic falls suggest that the latest eruption occurred in the last few centuries. Ground deformation and internal dynamics studies began in 1988-89. A physical volcanology observatory, consisting of tilt and seismic permanent networks together with GPS and gravimetric periodic networks were set up. In 1996 a multidisciplinary research programme grouping the previous activities and aiming at modelling the internal dynamic processes of the volcano started. Seismic, tiltmetric, GPS, gravimetric and magnetovariational measurements are underway in order to analyse the space-temporal pattern of the various parameters defining the state of "normality" of the volcano. Previous magnetic and gravity data were used to perform modelling studies. Furthermore, the development of a volcano control strategy, which may be adopted for other volcanoes with similar problematics but greater risk, is amongst the aims of this project. Multidisciplinary data collected during the last Italian Antarctic Expeditions will be discussed together with first results and future developments.

MONITORING GROUND DEFORMATION AT THE DECADE VOLCANO GUNUNG MERAPI, INDONESIA

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Pressure changes within a volcano lead to deformations of his edifice. To discriminate local and regional ground movements, four deformation stations with clusters of continuous borehole tiltmeters have been installed at the hillsides of Gunung Merapi. In addition, recording local environmental parameters allows the recognition of interfering local tilt signals. First analyses of the data records show: The significant tidal variations of the tilt signal validate the successfull coupling between the instruments and their surroundings. Transient tilt signals correlated to rainfalls are probably caused by poroelastic deformation of the hillsides. Four volcanic events occurred during the observation period; all of them were accompanied, if not triggered, by heavy rainfalls. Tilt anomalies, considerably larger than the rain induced tilts, were recorded around the event of October 31, 1996, coincident with an extraordinary high seismic activity. If this activity reflects internal fracture processes prior to the eruption, the accompanying deformations might partially explain the observed tilt signal.

LOCATION OF THE SOURCE AND SHALLOW VELOCITY MODEL DEDUCED FROM THE EXPLOSION QUAKES RECORDED BY TWO SEISMIC ANTENNAS AT STROMBOLI VOLCANO.

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In the framework of the seismic experiment carried out at Stromboli volcano in September 1997 two seismic antennas (300 m aperture) were set about 1500 m far from the active craters, in two different sites. 24 1 Hz sensors were used for Ginostra array, located in the western part of the island, while 32 4.5 Hz, extended to 1 Hz, were used for Semaforo Labronzo array, located in the northern flank. About 100 explosion quakes, contemporaneously recorded by oth the arrays, were analysed using the zero-lag cross-correlation method. Slowness and back-azimuth measured at the two antennas were used to obtain the location of the source. Velocity dispersion curves were obtained at Ginostra array using single station methods (MFT, PMF). The shallow shear wave velocity model for Ginostra, inferred from these curves has been compared with that obtained for Labronzo site. Results show that the explosion quakes are generated close to the active crater area. The velocity models give useful informations on the first 200 meters, showing in both sites a layered structure with shear wave velocity increasing from 500 m/s at surface up to 1500 m/s at 200 m depth.

PETROLOGICAL TRIGGERS TO VOLCANIC ERUPTIONS: SILICATE-CARBONATE MAGMA UNMIXING

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Field evidence and laboratory experiments on disaggregated mantle xenoliths in volcanics from Southern Italy show that volatile solubility in magmatic systems rapidly changes after two-liquid unmixing. In this model, a steady state process, such as crystal fractionation, drives an alkaline silicate magma to a two liquid immiscible state (silicate-carbonate). If melt segregation is rapid, which is likely due to different physical properties, then continued crystallisation of high temperature silicates from the carbonate melt can cause volatile oversaturation and development of a free vapour phase. Energetic release of the high pressure, vapour-charged system propagates eruption. Silicate crystallisation on, for example, conduit linings fluxed by carbonates results in rapid crystal growth, and may produce megacrysts. We have examined the role of alkalies on phase relations and liquid compositions in the simple carbonate-silicate system between pargasite-calcite. Vesiculation at shallow depths in volcanic eruptions is well understood, and may involve water table interaction. Our results are more applicable to deep pre-vesiculation events which occur at high pressures in the deepest crust of upper mantle and are expected to produce maar-type deposits.

TIME AND SPATIAL CLUSTERING OF ETNEAN SEISMICITY, 1981-1991

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The relations between seismic activity and flank eruptions at Mt Etna (Italy) have been investigated using fractal dimension analysis for the period 1981-1991, characterized by seven major flank eruptions and continued seismicity. The seismic data set can be considered complete from M 2.5, using the completeness test of Tinti and Mulargia (1985). The geometric fractal dimension D is evaluated by the correlation integral method (Grassberger and Procaccia, 1983), which gives weight to the number of elements inside each sampling box. The time and spatial evolution of the temporal fractal dimension D_t, calculated on a 40-seismic-events moving window, indicates a mid-term variation (timescale of years) related to stress conditions within the volcano and a short-term change induced by the approach to a flank eruption. The results are consistent with those from a similar analysis for the period 1874-1913 (De Rubeis et al., 1997). In addition, the spatial clustering of events can be attributed to three structural domains: Mt Etna itself, and the neighbouring Tindari-Giardini Line and the Western Iblean mountains. Such structural associations help distinguish tectonic and magmatic controls on seismicity and eruptions, so also helping to improve long-term assessments of volcanic hazard.

RISK EVALUATION WITH STOCHASTIC MODELS OF LAVA FLOWS

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Numerical models are commonly used for theoretical studies of lava-flow dynamics. Their application requires detailed knowledge of local factors, such as initial eruption conditions and topography. Since most of these factors are poorly constrained ahead of an eruption, such models have limited use for forecasting risk. An alternative approach is to treat a flow as a stochastic rather than deterministic system, so that its progress is determined by a set of guidelines in place of initial and boundary conditions. Flow advance is still governed by standard physical rules but its route is allowed to divert from the path determined by the strict deterministic solution. The probability that a flow takes a given path increases as that path more closely follows the deterministic route. By combining the outcomes of a large number of simulations, the stochastic approach provides a rapid, flexible and reliable means of preparing probabilistic vulnerability maps for a wide range of eruption scenarios.

LANDSCAPE RESPONSE TO AIRFALL DEPOSITS FROM LARGE EXPLOSIVE ERUPTIONS: AN EXAMPLE FROM CAMPANIA, S. ITALY

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The south-eastern sector of the Campanian Plain contains several alluvial fans of volcanoclastic material, located in a limited area bordering hills near the towns of Nola and Palma Campania. Several depositional bodies each form a single alluvial fan. The deposits consist of nearly homogeneous pyroclastics produced during large explosive eruptions from either Somma-Vesuvius or the Phlegrean Fields. U-shaped channels cutting the bodies indicate normal stream activity during intra-eruptive periods. Carbonate-gravel stream deposits followed by volcanoclastic debris-flows and hyperconcentrated flood-flows form the infilling sequence of each channel, often topped by sheet flow deposits. The alluvial bodies could have evolved over periods from months to tens of years, depending of the volume of pyroclastics and climatic conditions. The occurrence of such peculiar alluvial fans results from their location along the main dispersal axis for Phlegrean and Vesuvian fallout deposits, as well as to flat-lying relief in this zone. Understanding these deposits is important for assessing the mid-to-long term possibility of major flooding and lahar generation after large explosive eruptions from the Campanian volcanoes.

GAS CHEMICAL STUDIES AT MERAPI VOLCANO, INDONESIA

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A specially designed, automatic gas-measuring device, consisting of a gas chromatograph, an alphazintillometer and a temperature sensor, was installed at the summit of Merapi in May-June 1997. Over several days, the concentrations of H_2O, CO_2, SO_2 and H_2S were measured every 35 mins and those of ^{222}Rn and ^{220}Rn (Thoron), with fumarole temperature, every 70 mins. The data were sent via radio link to the Merapi Volcano Observatory in Yogyakarta. Gas and fumarole condensates were sampled conventionally and analysed for He- and H- and O-isotopes at the GFZ. The data show a positive correlation between SO_2 and CO_2, but negative correlations between these and H_2O. Gas concentrations pulsed every 3-4 hours, SO_2 and CO_2 increasing and H_2O decreasing, while gas temperature and the ^{220}Rn concentration both increased with increases in gas velocity. Increases in gas pressure associated with larger SO_2 and CO_2 fluxes may have induced rockfalls and related seismicity (Suharno, pers. comm.). The $^3He/^4He$-ratios of $8\text{-}8.8 \times 10^{-6}$ are typical for volcanoes at convergent plate boundaries. H- and O-isotope data from spring water and fumarole condensates indicate a dominance of meteoric over magmatic water. The results suggest that magma formation involves melting of the subducted Australian Plate (containing trapped ocean water). Fluids escaping from ascending magma are diluted by surface water, but their proportion helps constrain estimates of magma volume and may aid forecasts on long-term dome growth.

NH5 Geomorphological hazards: extent, evaluation and mapping techniques

Convener: Guzzetti, F.
Co-Convener: Allison, R.J.

INFLUENCE OF HEAVY RAINFALLS ON ROAD SAFETY

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The VERT Research Project, aimed at evaluating the influence of heavy rainfalls on road safety, has recently been funded by the European Community BRITE Programme. Within this Project an experimental campaign will be carried out to measure water thickness on in service road pavement surfaces under different rainfall conditions. The survey will be carried out without any interference with the traffic flow by means of a contactless technique based on video image analysis. A self activating monitoring station consisting of a videocamera, an automatic pluviometer, a disdrometer and a portable pc will collect the experimental data. The results will be analysed to find out possible relationships between the rainfall parameters (rain intensity, duration, impact energy) and the water film thickness measured analysing the videoimages of the water surface collected during the rainfalls. The experimental data will be compared with the theoretical ones predicted by a physical model developed within the VERT project. The model is based on the road surfaces geometric layout, pavement texture and rainfall intensity. The report will describe the experimental set up and will refer about the preliminary results obtained.

MEASUREMENT OF DEBRIS FLOW SURFACE VELOCITY BASED ON IMAGE PROCESSING TECHNIQUES

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Because of the great destructive power possessed by debris flows, that is often cause of severe damages to the properties on the fan of mountain torrents, measurements of their most important characteristics, such as flow height, impact force, velocity or volume are particularly important and might greatly help in the development of countermeasures and warning systems. Unfortunately in many cases devices, methods and procedures already developed and available for measuring analogous characteristics for clear water cannot be applied to debris flows. This is particularly true for the measurement of flow velocity, because of high flow density and the presence of boulders and smaller fragments within the moving mass that impedes the use of devices such as current meters, chemical tracers, weirs, flumes etc.. A new method based on the automated shooting of videos of debris flows and the subsequent use of image processing techniques to measure superficial velocities of debris flows is proposed. This method is based on the direct computation of the mapping between 2D image points and points in the 3D space without resort to a geometric calibration of the camera and of the scene. The method is applied to measure the surface velocities of a couple of debris flows that were video recorded in 1996 in north-eastern Italy.

REMOTE SENSING TO EVALUATE SOIL HYDROLOGICAL STATUS IN THE ARNO BASIN, ITALY

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Remote sensing can be a very interesting source of distributed data for large or medium scale hydrological modelling, where soil status and land conditions can be extremely different from one zone to the other and a large amount of in-situ measurement would be necessary. In this study two Landsat TM images of the lower part of the Arno basin [Tuscany, Italy] taken in 1991 were processed using several techniques. Cluster analysis gave interesting results in monitoring the state of soil and vegetation in the two different periods of the year. Clusters obtained have been compared with the distribution of different pedological classes and soil use and with geomorphological informations from the DTM. Landsat data were used also to obtain several soil water content indexes, and produce maps of soil moisture. A principal component analysis has been used to obtain data that are directly dependent on soil and the less influenced as possible by other factors like vegetation. Finally, an algorithm to retrieve soil hydraulic properties (permeability, gravitational storage, capillary storage) from geomorphological data (slope, aspect) and pedological class has been studied, using Monte Carlo simulation and optimization techniques. The spatially distributed soil hydraulic properties have been applied in a phisically based hydrological model. The results were compared with soil water content indexes obtained from Landsat data analysis on two sub-basins of the Arno river.

A NEW DATABASE FOR ENVIRONMENTAL RISK ASSESSMENT AND HAZARDS PREVENTION IN THE VENICE AREA

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A new database has been developed (this is the fourth version) to file and make available the information (data, images, mathematical models, bibliography, etc.) in the Venice area. The database has been set up by the Istituto Veneto di Scienze, Lettere ed Arti (a long-established Academy of Science) in the main web site http://www.ivsla.unive.it/slv. A work project such as this constitutes a challenge on account of its wide spectrum of knowledge and it will be effective only if it is continuously updated. The data base fulfils many aims, in particular it can be used: to organise the information collected; to promote the standardisation of the measuring techniques; to improve information-retrieval; to verify the feasibility of new projects; to find synergism between available data; to assess environmental risks and to prevent environmental hazards; to check safety measures step by step and in real time; to preserve administrative transparency for technical choices, and for other purposes too. Naturally the database we have in mind can give rise to problems as well as advantages; for example, the difficulty of collecting knowledge; problems in checking data quality and transfer protocols, etc.. The Venice lagoon is a very complex environmental systems affected by a great variety of natural and human factors which characterise the area as an exceptional laboratory useful for a multidisciplinary approach to environmental studies. The database is an example of co-operation among different scientific institutions with the aim of identifying, describing the greatest quantity of information possible in order to study the causes and effects of natural hazards in the lagoon and in the surrounding areas.

LANDSLIDE INVENTORY, DENSITY AND HAZARD MAPS: A COMPARISON

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Cartography is a crucial aspect of any landslide hazard assessment. Landslide maps most commonly prepared by geomorphologists are: landslide inventories; landslide density maps; and landslide hazard maps. Their purpose is to visualise the spatial distribution of landslides and to portray the associated hazard. Landslide maps can be prepared by a variety of methods depending on the scope, the available resources and the scale. Inventories are the simplest form of landslide mapping. They record the location of all landslides that left discernible features in the area. They may show the type of failure and the date of occurrence. Density maps are obtained by interpolating (in space) the information available from landslide inventories. Proper interpolation must be guided by geomorphologic constrains. Hazard maps show the distribution of landslide hazard inferred by direct mapping or thorough indirect, qualitative or quantitative modelling. Examples of different landslide maps prepared for the Umbria-Marche region of Central Italy are used to discuss the information content and reliability of landslide maps. In the attempt to limit the drawbacks inherent in any type of landslide map, and in order to maximise their information content, combination of different landslide maps are proposed and discussed.

THE NEW MAP OF SITES HISTORICALLY AFFECTED BY LANDSLIDES AND FLOODS IN ITALY

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In 1989 the Italian Minister of Civil Protection requested the Group for Hydrogeological Disasters Prevention to compile an inventory of information on areas historically affected by landslides and floods in Italy, for the period 1918-1990. Between 1991 and 1992 seventeen research teams worked on the project collecting information on mass movements and floods. A total of 22 journals were systematically searched and 350,000 newspaper issues were screened. About 150 expert witnesses were interviewed and more than 1400 published and unpublished technical and scientific reports were reviewed. Information on 11,000 landslides and on 500 floods were collected and stored into a computer database. A preliminary map of sites affected by mass-movements and inundations was prepared. Between 1994 and 1997 an effort was made to access the reliabilty of the archive as well as to update the inventory for the period 1991-1994. For the later, 55 local or regional journals, for a total of about 70,000 newspaper issues, were searched. Additionally, all sites known to have been affected at least once by mass-movements or inundations, were mapped at 1:100.000 scale. Main results are: an updated sinoptic map of sites historically affected by hydrogeological disasters; a comprehensive catalogue containing information on the location of about 30,000 sites; and CD-ROM based archive of the sites affected by mass-movements or floods. Despite the limitations inherent in a nation-wide inventory prepared by searching newspapers and chronicles, the mentined products represent the most comprhensive source of information on mass-movements and floods in Italy for this century. Further information can be found at the project web page http://avi.gndci.pg.cnr.it .

SPECTROMETRY TECHNIQUES FOR IDENTIFICATION OF EXPANSIVE CLAY SOILS AND DETERMINATION OF SWELLING POTENTIAL

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Swelling soils are a major geologic hazard, and expansive clays and clay-shales cause extensive damage world-wide every year. The cost of post-construction mitigation is prohibitive, and the costs of standard engineering soil tests and creation of regional maps is also very high. One example of this problem is the current situation in the Front Range Urban Corridor in Colorado which is underlain by Cretaceous clay-shales, furthermore with steeply-dipping bedrock strata. Smectite is the clay mineral group that has the greatest swelling potential and is responsible for most swelling soil damage in Colorado.
We are developing a field spectroscopic technique for *in-situ* determination of swelling soil potential. Near-infrared (NIR) reflectance spectroscopy of swelling soils samples shows that it is possible to discriminate among pure smectite and mixed smectite/illite layers samples, and to detect high water content by spectroscopic means. Spectroscopic identifications are well correlated with mineralogical x-ray diffraction analyses and geotechnical engineering tests.

DECONTAMINATION SIMULATION BASED ON DETAIL CS-137 SOIL CONTAMINATION MAPS

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Vast areas contaminated from accidents at the Chernobyl NPP and the "Mayak" facility require the decontamination actions now. An effective measuring method of a 137-Cs soil deposit in-situ is developed for detail mapping of the these areas. Using this method an electronic contamination maps (scale 1:5000 or 1:2000) for settlement Haltch (Gomel region of Belorus) and the Techa river flood plain near Muslumovo (Chelyabinsk region of Russia) are made now. They may be considered as a separate contamination levels of GIS developed for these areas. Based on contamination maps a decontamination simulation of these territories was carried out. A maps of equivalent dose rate (EDR) distributions were calculated for two decontamination procedures: the removing of upper contaminated soil layer and the covering of them by clean sand. A total volume of soil removed and clean sand of covering was calculated too. An efficiency of decontamination is calculated as a relation of average EDR before and after decontamination. Other possible approach of decontamination actions is to reach a safety EDR level at the considered area. Results of simulation of these actions are presented as a calculated map of soil layer thickness which should be removed for reducing of the EDR down to the level required.

EVALUATION OF FLOODPLAIN CHANGES AND GEOMORPHOLOGICAL MAPPING OF THE COASTAL ZONE PLAIN OF MYZEQ (ALBANIA) USING LANDSAT TM IMAGERY

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The coastal plain of Myzeq is the largest coastal plain in Albania, having a surface of about 1900 sq.km. It includes three main rivers (Shkumbini, Semani and Vjos') and two coastal lagoons of economical and ecological significance (Karavasta and Nartes). Since the end of World War II the area has been affected by reclamation of floodplains and wetlands, creation of artificial canals for irrigation, agricultural practising and considerable coastal changes. A geomorphological evaluation was carried out using Landsat TM imagery covering a 10-year period (1986 and 1996) to discriminate between areas dominated by river flooding and areas subjected to coastal processes. Further information on land reclamation and coastal erosion/accretion were obtained from historical maps and orthogonal aerial photography. The study discovered that a large part of the floodplain along rivers has been transformed into agricultural land and most of the coastal wetlands along the lagoons have been reclaimed. It was noted that the three rivers in the area have proved to be extremely active and likely to rapidly change their courses as it happened in the years 1962-1963 when exceptional floods took place. The floodplain along the rivers was divided into landscape units according to what extent is at present controlled by river processes. Buffer areas along river courses were identified to produce a flood susceptibility zonation suitable for planning purposes.

TECHNIQUES FOR HYDROLOGICAL RISK ASSESSMENT IN CIVIL PROTECTION PLANNING

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Emergency planning represents an essential tool for an effective management with regard to hydrological risk. Through a careful analysis of dangerous conditions a set of possible scenarious was prepared. Scenarious are used to organised the assistance activities and to make previsional system work. Unfortunately, at present, in Italy techniques for hydrological risk evaluation that can be applied in civil protection plannig are not consolidated. Starting from a real civil protection plan a standard procedure, limited to particularly urban conditions, was prepared. The Plan focus on strategies for using physical, social and economical parameters to identify the best strategy in order to minimize the expected damage. The study provides the opportunity to test new procedures for the production of emergency plans and operational sequences that have to be managed by local authorities before, during and after the event. The example provides guidelines to be used in the given urban condition.

EVALUATION OF STREAM AND DEBRIS FLOW HAZARDS ON SMALL FANS ALONG THE INTERSTATE-70 HIGHWAY CORRIDOR, CENTRAL COLORADO, U.S.A.

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Preliminary results from a U.S. Geological Survey study of small (<0.5 km^2) fans along a 23-km portion of Interstate Highway 70 show a moderate potential for hazardous stream and debris flow activity. The study area is west of Denver, Colorado, one of the fastest growing metropolitan areas in the U.S., and transects the Front Range portion of the southern Rocky Mountains along Clear Creek, an east-flowing, formerly glaciated drainage. Morphometric analysis utilizing Melton's basin ruggedness number and fan slopes, combined with fan classification based on sedimentological observations, suggests that about 60% of fans are of debris-flow origin, 30% of stream-flow origin, and 10% of mixed origin. Fan slopes become steeper and drainage basins become more rugged above the line of maximum glacial extent. Historical records from the last 100 years indicate multiple depositional events on fans from south-flowing tributaries. Detailed subsurface mapping and radiocarbon dating of fans from north-flowing tributaries suggest that the last major phase in depositional activity was between 1250 and 1450 AD. Results from several fans suggest that late Holocene activity is distinguished from early Holocene activity by lower accumulation rates (0.2-0.4 vs. 0.4-0.6 mm/yr.) and longer recurrence intervals (200-5000 vs. 100-2000 yrs.)

ROCK-AVALANCHES AS EVIDENCES OF PALEOSEISMIC ACTIVITY IN THE SIERRAS PAMPEANAS, ARGENTINA

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The Sierras Pampeanas are basement uplifts located in Central Western Argentina where considerable neotectonic activity took place during Pliocene-Pleistocene times. Quaternary faulting along these ranges uplift front as well as some historical earthquakes indicate that paleoseismic records should be studied for a better understanding of the regional seismic hazard. Two rock-avalanches have been recognized at the northern piedmont of the southernmost Sierra de San Luis. Differential preservation of their geomorphological attributes suggests different ages. Avalanche accumulations are characterized by large blocks. Deposits and morphologies belonging to the older one are not well preserved, hampering the reconstruction of their morphometric parameters. However, deposits signature as well as the direct relationship with a hillslope scar clearly indicate a rock avalanche nature. The younger one still shows its original morphological features, allowing the calculation of its volume, velocity, area covered, thickness and maximum run-off. Avalanche volumes, morphotectonic location, morphometric parameters and isolated occurrence, favour the association of these geomorphological features with a seismic origin. This fact open some interesting points as for the regional seismic hazard characterization such as: earthquakes with capabilities for movilizing important volumes of rocks took place during the Quaternary; no rock avalanches were induced as a consequence of the nearby 1936 San Francisco earthquake M=6.0.

EVALUATION OF MECHANISM OF EARTHQUAKE-INDUCED LANDSLIDES BY ADVANCED RING-SHEAR APPARATUS

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Landslides triggered by earthquakes occurs in seismically active regions in the world and causes numerous casualties. The Nikawa Landslide induced by the Hyogo-ken Nanbu earthquake on 1995.01.17 in Japan killed 34 people. Despite significant progress achieved during last decades in the field of prediction and mitigation of landslide risk, scientists are not able to cope with earthquake-induced landslides because: a) time of tremor itself couldn't be predicted and b) mechanism of initiation of such landslides is different from conventional landslides.
In order to investigate the latter factor, new and advanced type of ring-shear apparatus was developed by second author with colleagues. The using of this device provides unique possibilities for researcher to carry out complicated experiments with various schemes of loading and parameters measuring. Based on the results of tests conducted by new ring-shear apparatus several new phenomenon were observed and certain progress in evaluating of seismic-induced landslide was reached.

SEMI-AUTOMATIC TEXTURE SEGMENTATION OF REMOTELY SENSED IMAGERY FOR LANDSLIDE HAZARD ASSESSMENT

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Image segmentation implies the division of the image into regions of similar attribute, where texture can be taken as such attribute. On remotely sensed imagery of landslide-prone areas texture is often the expression of specific landforms and/or vegetation disruption patterns encompassing landsliding. In this paper a semi-automatic texture segmentation approach for recognising unstable slopes is presented. The method entails three main stages: i) selection of training samples; ii) texture transformation based on the image texture spectrum; iii) thresholding of the texture image into discrete landslide hazard zones. This technique has been applied to both air-borne and satellite-borne panchromatic and multispectral digital image sets at resolutions ranging from 3.5 m to 30 m, including ATM, IRS-1C Pan, SPOT Pan and Landsat TM imagery of a semi-arid Mediterranean area. On multispectral imagery, discriminant analysis is further undertaken for selecting the best texture-based segmented bands. Adequacy of spatial resolution and spectral coverage for discriminating landslide-related texture on imagery is also discussed.

GEOMORPHOLOGICAL SURVEY AND GIS TECHNIQUES AS A TOOL FOR PREDICTIVE EROSION MAPPING

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In semiarid central-western Argentina, rainfall are enough to produce runoff, but still scarce to generate a protective vegetationl cover. Fifteen percent of the country is prone to erosion by water and this affects specially the scarce productive areas of this region. Erosion is principally significative nearby the border of the San Luis range and it is developed in loess cover overlying a Tertiary paleo-landscape gently undulated. The southeastern range margin is characterized by a high-density of gullies, some of them forming ravines and hence disabling many areas for agricultural laboring. Detailed geomorphological cartography is being developed with the aim of determining the type, degree, evolution and distribution of erosional activity. Working methodology includes the definition of cartographic units through to ITC System of geomorphological survey, where the major units are delimitated considering morfogenetic issues. These units were determined based on aerial photos and TM imagery with scales ranging from 1:20,000 to 1:100,000. Other variables such as lithology, climate, soils, topography, vegetation and land use have been considered in order to evaluate the erosion phenomena. This information has been organized in a database, with the aim of employing GIS capabilities. By overlaying GIS cartographics functions, geomorphological units were related with gully distribution and enviromental data in order to recognize the degree of coincidence among them. This procedure is a first approach for achieving empirical rules which can lead to build predictive models.

ELEMENTS OF RISK MAPPING FOR RAPID LANDSLIDES

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Rapid landslides can move over considerable distances and pose danger to areas remote from the location of instability. In such cases, the risk assessment must include the determination of the following: 1) Magnitudes and probabilities of the full range of possible initial detachments. 2) A spectrum of velocities, reach distances and damage corridor widths. These are obtained by applying suitable runout models to the events identified under 1. (This step may be refered to as intensity determination.) 3) Vulnerabilities of elements at risk to the intensity distributions obtained in 2. 4) Estimates of specific risks and their accumulation to obtain the total risk. This analytical chain is very complex and difficult to connect, particularly as many of the tools required to accomplish the individual tasks are poorly developed. The analysis can be approached from two directions. The potential of the source areas to generate landslide events can be studied first ("stability analysis") and the risk assessment is carried out in the order presented above. Alternatively, an inverse approach can be taken, where past impacts in the hazard area are studied and a magnitude-frequency relationship is derived backwards from such data. Two examples will be given. The first is the risk assessment on a large fan subjected to volcanic debris flow hazards. The second is a calculation of risks arising from rock falls of different magnitudes and frequencies, reaching a busy highway.

THE STUDY OF LAND SUBSIDENCE IN THE REGIONS OF SOFIA, SKOPJE AND TIRANA

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The Project of BAS-UNESCO had permitted the starting of the international investigation about the expert assessment of the land subsidence in the three Balkan big cities. The causes of the land subsidence are not only the hydrogeological characteristics, but also the engineering geological conditions. The last ones include the different peculiarities of the soils and the rocks, the influence of the gravity processes, the processes of the karstification, the neotectonic mobility, the seismic activity.

Two Meetings were realised, respectively in Sofia (1996) and Skopje (1997). Their materials were published. The main scientific conclusions shown that in the three big cities the favour for land subsidence natural factors are going in combination with technogenic ones.

ANALYSIS OF SLOPE GRADIENT ANTECEDENT TO LANDSLIDE FOR PRIMARILY SLIDE SUSCEPTIBILITY MAPPINGS

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Mapping of the areas with unstable slope is important to decide the priority of slope stabilization works, as well as to plan warning and evacuation for residents, railroads, highways etc. In this situation, topographical factors have been adopted in order to investigate landslide susceptibility with geological and meteorological ones. In this study, "Slope gradient antecedent to landslide" discussed as a index in susceptibility investigation for primarily slides which are up to certain percentage of landslides(40% in Japan.) In this context, it is necessary to have the slope angle (antecedent and post-slide) . Hence, antecedent slope angle θ_0 and post-slide angle θ are investigated with several landslides including some historical ones that are restored using "Critical Slip Surface Analysis by Dynamic Programming(CSSDP)", historical records, geological knowledge. The CSSDP can search the critical slip surface which has minimum factor of safety(Fs) in given slope structures. Consequently, the slope ratio $\Gamma = \theta_0 / \theta$ of 0.8 $\leq \Gamma \leq$0.9 was gained as average values for all geology.

It is a important information to detect the susceptible slope relevant to primarily landslides.

GULLY EROSION IN VINEYARD PARCELS IN THE NE SPAIN. A STUDY OF DETERMINING FACTORS.

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Vineyard cropping systems and terrain characteristics in the NE Spain Mediterranean area favour gully development. Many parcels have been redesigned to achieve longer vine rows and lower slope degrees to facilitate mechanisation. This has implied huge soil movements that have not been effective to avoid gully erosion. To know about gully erosion related factors in vineyard parcels of NE Spain Mediterranean area, two representative catchments, of approximately 20 km2 each, in the Alt Penedes-Anoia region were studied. A total of 40 parcels (20 with evidences of gully erosion and 20 without evidences) were sampled, taking easurements of slope length, degree and form, aspect, vine rows orientation, flow concentration in the parcel, connection of channels to main networks, soil characteristics, erosion control measures, etc. The statistical analysis reveals slope degree and terrain roughness as the most important terrain related determining factors; and top layer haracteristics as clay content, organic matter content and surface stoniness as soil related determining factors. Regarding vineyard management practices, convergence of water flow in drainage channels and terraces, and presence of areas with incoherent materials are the most important factors determining gully erosion. This study was carried out within a GIS environment, and the output information can be used for effective gully control plans and vineyard parcel design in Mediterranean area (NE Spain).

MODELLING THE INFLUENCE OF VEGETATION CLEARANCE IN THE OCCURRENCE OF SHALLOW LANDSLIDES

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Several previous studies have found that the removal of a dense vegetation cover often leads to slope instability. In the short term it increases the receipt of precipitation at the ground surface, which can result in accelerated erosion as well as shallow landslides. In the long term, with a gradual decrease in root strength, it may also cause deep landslides. The landslide susceptibility of an area around Monte Nerone, in the Umbro-Marchean Apennines (Italy) was estimated using generalised linear modelling. Geological and geomorphological slope features were stored in a GIS database (Atkinson and Massari, 1998; Massari and Atkinson, submitted). Modelling results confirmed that, particularly for landslides on earth, going from bare soil to ploughed ground, uncultivated, pasture, open forest and forest, there is a clear decrease in landslide susceptibility. Since 50% of the area studied is at present covered by forest, a change in land use of these areas would increase their landslide susceptibility. The statistical model obtained from past earth-slumps and earth-flows was applied to present and possible future conditions. This allowed the forecasting of the effect of vegetation clearance on landslide susceptibility, and the mapping of the most sensitive areas. Overall, around 30% of the area now covered by forest would become unstable. Particularly sensitive are those areas where predominantly marly formations outcrop.

MODELLING THE PROBABILITY OF GULLY DEVELOPMENT IN VINEYARD PARCELS.

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An important extension of the NE Spain Mediterranean area has a high risk of gully erosion due to rainfall and lithological characteristics. In some regions, as the Alt Penedes-Anoia (Catalonia), specific land uses as vineyards contribute to increase the risk. This study presents a method to model the risk of gully development in vineyard parcels. The risk is evaluated in terms of the probability that ephemeral gullies develop in a parcel, depending on terrain and cropping system variables. A total of 40 parcels (20 with gully erosion and 20 without) were studied and sampled according to a list of 33 variables (relief, soil, cropping system and management practices characteristics). To identify the factors explaining the existence of gully erosion (considering correlation between factors), a stepwise selection was performed. The selected factors, slope degree and slope form in this case study, were considered as variables in a logistic regression of binary response. This produced an equation that computes the probability of gully development with a Good-of-Fit value of 0.842. The method was implemented in a raster based GIS, and the terrain variables for the application of the model were obtained from a 25 m resolution DEM. The validation of the model in other 52 parcels yielded an overall accuracy of 84.6%. The risk of gully erosion increases with the slope degree in an exponential way and from convex to concave contour form.

INDIRECT EVALUATION OF EROSION USING DEM AND REMOTE SENSING TECHNIQUES

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The evolution of dynamical land processes and soil erosion which are strong responsible for landscape modification in the river watershed, require intense monitoring activities. The use of GIS is a consolidated technique in the study of hydrogeological hazard within a specific hydrographic unit. A correlation analysis between different quantities derived essentially from geomorphology and remote sensing data, was accomplished, in order to archieve indirect and synoptic evaluation of the erosion occurring in a watershed. To the aim a DEM was applied to a quantitative empirical model for the hydrographic network analysis, to archive geometric information about drainage density, tributary hierarchization and morphometric parameters. Secondarily, LANDSAT-TM and aerial image spectrometric data were considered for physical and environmental evaluation. The explored methodology consists of correlating different observations spatially distributed, starting from the divide line down to the estuarine zone, The availability of hyperspectral data from MIVIS surveys, almost in relation to the satellite overpass, becomes a unique opportunity for a description of the dispersion of suspended load in the river plume and to assess its relationship and impact onto the sea coast. The study area is the Esino rivershed (central Italy), facing to the Adriatic sea.

CONTRIBUTION OF DETAILED SURFICIAL MAPPING IN THE RECONNAISSANCE OF MULTI-EVENT LANDSLIDES IN POSTGLACIAL MARINE CLAYS

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Landslides in the Chicoutimi-La Baie area, central Québec, have been mapped at two main scales: a local detailed scale (1:1 000) for urban engineering and geotechnical purposes and a more regional scale (1:50 000) for earth scientists and land use planners. However, systematic surficial mapping using black and white aerial photographs at a scale of 1:15 000 has proven to be a more efficient method to investigate and understand the complex history and distribution of multi-event landslides. These landslides occur in thick marine clays that were deposited in Laflamme Sea between about 10 250 and 8 500 years B.P. Marine regression has left a series of stepped marine terraces at elevations ranging from 160 m down to modern shores of the Saguenay fjiord. Detailed cartography shows that the regional scale (kilometric) landslide scars are laterally associated to some marine terraces and that a robust relative chronology can be established for large sets of landslides mainly on the basis of the staircase distribution of multi-scale scars.

GEOMORPHOLOGICAL MAPPING AND GIS TECHNIQUES FOR PREDICTING GEOMORPHOLOGICAL HAZARDS

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This paper focuses on the fact that the prediction of geomorphic hazards needs the complementariety of geomorphological mapping and GIS. Several maps of the Central Spanish Pyrenees and the Iberian System have been elaborated at a 1:50,000 scale, including very heterogeneous topographic conditions and a great variety of lithologies. All the mass movements (planar slides, slumps, terracettes, solifluction lobes, debris flows) have been digitized. At the same time land-uses, plant cover, gradient and exposure maps have been also elaborated and all the information implemented in a Geographic Information System. The use of multivariate statistical procedures allows us to predict the most hazardous areas with a high confidence level.

GEOMORPHOLOGICAL HAZARDS FROM THE POSSIBLE SEA-LEVEL RISE: CASE STUDY FOR THE SEA OF AZOV

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Possible sea-level rise will afffect sea coasts not only by passive inundation but, to the much greater extent, by various types of geomorphological reformation. An integrated methodology for assessment of change on sea coasts under the possible accelerated sea-level rise in the nearest decades is presented. The methodology is based upon the concept of various morphodynamic types of sea coasts and a probabilistic prediction of shoreline retreat values. Both palaeogeographic data and direct observations are used to establish patterns and intensity of coastal morphological changes. A case study analysis for the coasts of the Sea of Azov in the borders of Russia under the 1-meter global mean sea-level rise by 2100 is presented. Loess escarpments and drift-aligned sandy spits will be most vulnerable to this process. In several segments of the coastal zone, morphological changes will possibly become catastrophic. Shoreline retreat by the end of the 21st century can be as high as 300-500 m for erosinal scarps and over 1 km for depositional bodies. Total economic losses otal economic losses from the sea-level rise can be as high as US$ 3,000,000 per a kilometer of shoreline length.

GEOMORPHOLOGICAL MAPPING FOR LANDSLIDE HAZARD ASSESSMENT IN THE DOLOMITES (ITALY)

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The authors describe the mapping methodology adopted for landslide hazard assessment within the framework of the Newtech Project, funded by the Environment and Climate Programme of the European Union.
The work is carried out in three phases.
The first phase consists of a geomorphological analysis of the study area that allows a *standard geomorphological map* on a 1:25.000 to 1:10.000 scale (1) to be laid out. The data obtained can be implemented into a GIS.
The second phase consists of a slope instability analysis which is divided in two parts. One part is a *geomorphological map applied to slope instability analysis* on a 1:5000 scale (2a) which derives from the standard geomorphological map throughout the identification and the further characterisation of unstable areas of different degree of activity. The other part is a document containing *geotechnical and geomechanical data* (2b) that permits the causes and the evolution of landslides to be better understood and characterised. The data obtained can be implemented into a GIS.
The third phase consists of a *landslide hazard map* containing two basic elements: *landslide phenomena* (3a) and *landslide prediction* (3b). The first element is obtained from map 2a throughout data processing and selection for landslide purposes: it depicts the spatial and the temporal distribution of landslides in the study area, thus the effects of slope instability. The second element is obtained throughout the identification of the causes of each type of landslides and by means of comparisons and analysis based on statistical models supported by a GIS; it depicts land subdivision in stable and unstable areas.
The poster illustrates the various phases of the methodology with particular reference to the area of Corvara in Badia (Dolomites).

CONTROLS ON GEOMORPHOLOGICAL EFFECTS CAUSED BY CATASTROPHIC FLOODING IN A SMALL MID-MOUNTAIN DRAINAGE BASIN

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Geomorphological mapping was carried out in a small mid-mountain drainage basin in the East Sudetes, SW Poland, in order to identify geomorphic changes resulting from the catastrophic rainfall and floods in July 1997. Spectacular landscape changes due to erosion and accumulation were the consequence of abnormally high discharge, estimated to be at least 90 times higher than the mean discharge. Intensity and character of geomorphological processes were primarily controlled by three factors: (1) geomorphological setting within the catchment, (2) anthropogenic influence on the environment and (3) natural vegetation cover. The longest avulsion of the river as well as the most intensive lateral erosion, have taken place in the alluvial fan setting below a high fault-generated mountain front. The river has changed its planform from a single channel pattern into the braided one and destroyed the village situated at the foot of the mountain front. Upstream from the mountain margin, in valley sections with the slope exceeding 30‰ downcutting and, occasionally, mass movements on the valley sides have dominated. In the lower course of the river erosion has not been significantly active. Distribution of gully erosion and sheet wash was controlled by the degree of human impact on mountain slopes.

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CONVEYING SCIENTIFIC INFORMATION TO THE USERS: THE EXPERIENCE OF THE GNDCI INFORMATION DELIVERY SYSTEM

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The Italian National Research Council, Group for Hydrological and Geological Hazard Prevention (CNR-GNDCI) has developed and maintains a web site (http://www.gndci.pg.cnr.it/) and a set of data-bases (http://wwwdb.gndci.pg.cnr.it/) distributing information on hydrological and geological hazards. The aim of the system is to disseminate a vast amount of data, information and expertise to civil defence authorities, expert users, the media and the general public. Databases presently available include: addresses of research teams currently active within GNDCI; the list of GNDCI publications and reports; the IRP Library data-base; the AVI inventory, containing historical information on more than 10,000 landslides and 5000 flooding events occurred in Italy in this century; and mean daily discharge values for 70 gauging stations in Central Italy. The system, exploiting the potential of Internet and of new software tools, allows both the retrieval of hypertext documents and to perform remote queries, either pre-defined or free; the later using the SQL language. Query result provide the opportunity for submitting new queries by pointing and clicking, making informatio retrieval quite efficent. Current activity aims at: including new data-bases on historical discharge and rainfall data; preparing functions for generating summary reports; producing maps at various scales.

COPING WITH FLOODS: A PROPOSAL FOR A MUSEUM IN FLORENCE

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This paper is dealing with the proposal of a particular kind of museum which firstly aims at contributing to the birth of an environmental culture through the complete documentation over the floods in order to cope correctly with these natural hazards. This exhibition is focused on the hazards of the City of Florence and is build in way to be satisfactory for both the general attendance, as tourists and scholars, and the specialist one, as scientists and researchers. The museum space is arranged around a large scale model of Florence particularly designed to simulate the flooding phenomena through the town, allowing the calibration of more sophisticated mathematical models. Thus, it is twofold the function of such a structure: didactic and scientific at the same time. Moreover, the museum shows the aids of real-time monitoring systems to control the catchment hydrological behavior; a lot of documentation is collected to illustrate the geomorphological and historical aspects of the flooding in the Arno basin. Interactive spaces are also planned: virtuality and multimediality can well play a determinant role in the sensibilization of the visitor.

A MAN-MACHINE CONVERSATION MODEL FOR REAL-TIME MANAGEMENT OF EMERGENCY SITUATIONS

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Computerized decision-support tools are difficult to manage without full understanding of all model complexities. This fact limits their real-time use by decision makers, who usually are inexperienced users of these type of models. In this paper, a knowledge-based conversation model between man and machine for emergency situations is proposed. The model is conceived to support human operation of an emergency situation (flood, chemical spill, forest fire, etc.) in connection with a telemetry system and an underlying model of the physical process. Emphasis is placed on transfer of information to the user. The user can get answers from the model regarding two areas of decision: (1) what events are happening or may happen and why; and (2) what decisions to take, what will be their consequences and why. These questions may be referred to different spatial and temporal environments.

3-D VISUALISATION OF A TORNADO GENERATING MULTI-CELLULAR HAILSTORM

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Severe convection and associated phenomena (heavy precipitation, hail, gust fronts, downbursts, vortices, tornadoes) are complex and multi- dimensional. To improve our understanding of severe convection, one requires multidimensional measurements of key parameters (such as radar reflectivity and Doppler velocity) and it is desirable to have sophisticated computer tools for visualisation and efficient analysis of the data. The latter tools enable the scientific results to be encapsulated and communicated effectively to a larger public.

Here an approach is shown for the direct visualisation of three-dimensional computer animations of radar measurements of a severe hail- and windstorm that occurred in Northern Switzerland on July 22, 1995. The storm spawned a downburst/tornado that left a significant "damage track" of about 15 km in length and some 100 m in width. Volumetric radar data (radar reflectivity, Doppler velocity, vortex signature, shear zones every 2.5 min.) of the developing and evolving hailcloud are processed on a workstation with the Argos visualisation software. The animation displays the observed phenomena in a realistic framework (high-resolution rendering) and an intuitive approach towards a better understanding of the thunderstorm structure and its evolution is achieved.

INTEROPERABILITY SYSTEMS FOR SUPPORTING DECISION-MAKERS IN THE ENVIRONMENT SECTOR

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This paper is meant to describe the E-Mail project, funded by the European Union within the Telematics Application Programme - Environment Sector. The project is carried out by an international consortium of partners for developing of telematics applications for the support of decision-makers within public administrations in the environment sector. The E- MAIL applications are designed in order to assist in environmental monitoring and planning by means of data set provided by different sources, processed through an integrated set of tools. The objective is to provide the users with efficient tools to deal with environmental planning and management, e.g. water resources management, pollution and industrial risks. Such tools are developed in order to implement interoperability among heterogeneous environmental systems, adopting a high-level geomatic model. A survey on the present main geomatic standardisations was carried out, and an OGIS main model has been adopted along with the CEN-TC287 meta modelling approach. E-MAIL activity is carried out through four countries, Italy, France, UK and Greece; each country develops a particular application according to the needs surveyed within the involved public administrations. As far as Italy is concerned, a demonstrator is being built for the management of hydraulic risk planning in cooperation with the Arno River Basin Authority and the Tuscan Regional Government.

INFORMATION DISSEMINATION OF THE SEISMICITY OF ITALIAN AREA THROUGH THE GNDT WEB SITE

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The GNDT web site supplies information and results of activities and investigation carried out by GNDT - Gruppo Nazionale per la Difesa dai Terremoti (Italian National Group for Protection against Earthquakes). Aim is to exploit the potential of Internet as the main means of disseminating data and making information and databanks available to expert users - seismologists, geologists and engineers - not excluding civil defence officers and general public. On the web site, progressively developed during 1997 at http://emidius.itim.mi.cnr.it/GNDT/home.html, some GNDT projects concerning the seismicity of Italian area - parametric earthquake catalogue, intensity databank, seismogenic zones, seismic hazard, expedite damage scenarios, Catania project, maximum observed intensities in the Italian communes - and the web on earthquakes of September/October 1997 in Central Italy are available. Earthquake catalogue of nearly 2,400 damaging events from 1000 to 1980 and intensity databank containing 36,000 intensity datapoints referring to nearly 10,000 localities are stored as databases on which remote queries can be performed selecting parameters and views of interest through a user-oriented interface.

DO WE NEED A NATURAL HAZARD JOURNAL?

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The Interdisciplinary Working Group on Natural Hazards of EGS is developing, and the question of the existing Journals dealing with our problems has to be discussed. The technical and scientific contents of the existing journals and periodical publications are shortly reviewed. From such an analysis it is made evident that the broad scope makes difficult to maintain a high standard: the hope that good disciplinary con tributions are capable to produce good interdisciplinary interactions is definitely failing. The experience of the Italian Research Groups for Prevention from Hydrogeological Hazard, Earthquake Hazard and Volcanic Hazard is shortly discussed. In the field of Natural Hazards the scientific communication should help to efficiently exchange ideas, not among scientists in the same discipline, but across scientists of different disciplines. If a Journal is the best tool to do so, and how to control its quality and efficiency, is a matter of discussion.

DEVELOPING AN AGROMETEOROLOGICAL INFORMATION SYSTEM TO MITIGATE THE EFFECTS OF DROUGHT

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Drought is a recurrent feature of the Hungarian landscape. Since the early 1980s, droughts have resulted in severe losses in the agricultural sector with serious consequences on the national economy. These severe droughts have coincided with the transition of the economy towards a market-based economy with widespread private ownership. The Hungarian Meteorological Service has initiated a 3- year project with the U.S. National Drought Mitigation Center to modify and update the current agrometeorological information system to deliver a suite of timely products to users in the agricultural sector. These products (e.g. soil moisture maps, precipitation updates) will help agricultural producers make timely decisions aimed at reducing the effects of drought. This paper will report on the objectives and progress to date in the development of this agrometeorological information system.

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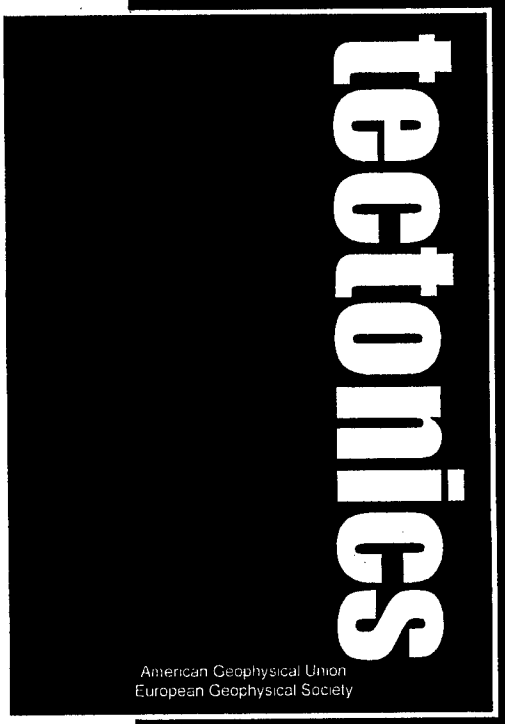

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View the three most recent tables of contents, learn more about the editors, and submissions, or subscribe on the web.

Code: EGS

European Geophysical Society

1998 Membership Application and Journal Subscriptions

General Information

The EGS is a pan-European, international scientific society for the promotion of the physics of the Earth and its environment and of planetary and space sciences.

The EGS serves the scientific community through its general assemblies and other meetings, its scientific journals and bookseries, its bulletin Newsletter, its special discount and subscription programmes, its support programmes in particular for young scientists and for colleagues from eastern Europe, its award programmes, and its many other activities.

Members of the EGS enjoy the following benefits:

- Newsletter, EGS's quarterly bulletin carrying articles on the results of recent research, upcoming meetings, as well as Society's news.
- Greatly reduced subscription rates to 10 journals of the EGS, which are all refereed and at no page charges for authors.
- 30-35% discount on all EGS books and on books published by the EGS publishers.
- Lower registration rates at meetings sponsored by the EGS. Abstracts submitted for the EGS General Assemblies are included free of charge in the annual supplement of the EGS journal *Annales Geophysicae*.
- Participation in the Plenary Session and in the Scientific and Technical Committees of the Society; possibility to stand for election for an office.

Membership

General Information

Membership of the EGS is by payment of an annual membership fee and is open to individuals or organizations professionally engaged in or associated with geophysics and related studies.

Membership is on a calendar year basis. Membership applications received after 1 October will be made effective as of 1 January of the following year, unless otherwise requested. Annual invoices requesting payment of membership fees and subscription to EGS journals are sent out at the end of the preceding year.

Members of all categories will receive their annual EGS Membership Card once their payment has been received.

Individual Membership

Regular Membership
is available to all individuals.

Student Membership
is available to students, who should enclose a certificate of their status when applying for student dues.

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is available to individuals, who have formally left their official scientific positions.

Life-Time Membership
is available to individuals by a one time payment in lieu of annual dues.

Affiliated Membership

is available to individuals, who are already members of an organization officially affiliated with the EGS. This affiliation is by application only and without any additional charges for the applying organization. Affiliated members enjoy a ⅓ reduction in their regular membership fee.

Corporate Membership

is available to the entire membership of an organization officially corporated with the EGS. The reduction for corporate membership in comparison to regular membership is ⅔, and the fee is paid annually en-bloc by the organization. The status of corporation is by application only and without any additional charges for the applying organization.

Journals

General Information

There are no page nor handling charges and reprints are, in general, free for authors in all EGS journals. Rapid publication and distribution worldwide, moderate library subscription rates and greatly reduced membership subscription rates are guaranteed.

All journal papers undergo rigorous peer review and careful copy-editing by competent colleagues prior to publication.

Annales Geophysicae *(12 issues/year)*
The leading interdisciplinary, boundary-layer journal covering the physics and chemistry of the oceans, of the lower, middle and upper atmosphere of the Earth, of the Sun and of the interplanetary medium, as well as the marine boundary layer and the air-sea interface, the interface between the atmosphere and the biosphere, lithosphere, hydrosphere, ionosphere and magnetosphere and solar-terrestrial interaction.

Subscription Rate			Postage Surcharge
Member	DEM	150,-	incl.
Student	DEM	75,-	incl.
Em. Sc.	DEM	75,-	incl.

Climate Dynamics *(8 issues/year)*
Welcomes papers containing original diagnostic, analytical or numerical modeling research on the structure and behavior of the atmosphere, oceans, cryosphere, biomass and land surface as interacting components of the dynamics of global climate as well as contributions focused on selected aspects of climate dynamics on particular scales of space or time.

Subscription Rate			Postage Surcharge
Member	DEM	98,-	Surface mail: DEM 34,-;
Student	DEM	98,-	Airmail (outside
Em. Sc.	DEM	98,-	Europe) DEM 53,-

Geophysical Journal International *(12 issues/year)*
Covers all disciplines of the physics and chemistry of the solid earth.

Subscription Rate			Postage Surcharge
Member	DEM	150,-	incl.
Student	DEM	55,-	incl.
Em. Sc.	DEM	55,-	incl.

Hydrology and Earth System Sciences *(4 issues/ year)*
The international and interdisciplinary journal for the publication of original research in hydrology, viewed as a separate geoscience alongside the atmospheric, ocean and solid earth sciences. HESS serves not only the community of scientific hydrologists, but all geoscientists who wish to publish new findings on the interactions between hydrology and other physical, chemical and biological processes within the Earth System.

Subscription Rate			Postage Surcharge
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Student	DEM	140,-	Europe) DEM 16,-
Em. Sc.	DEM	140,-	

Journal of Atmospheric Chemistry *(9 issues/year)*
The key journal for the study of the chemistry of the Earth's atmosphere with emphasis on the region below about 100 km, including also topics related to meteorology, oceanography, soil science and biology.

Subscription Rate			Postage Surcharge
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Student	DEM	240,-	incl.
Em. Sc.	DEM	240,-	incl.

Journal of Geodynamics *(8 issues/year)*
The interdisciplinary journal for solid earth research in geodetic, geophysical, geological and geochemical geodynamics, in particular of large scale processes.

Subscription Rate			Postage Surcharge
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Em. Sc.	DEM	110,-	incl.

Newsletter *(4 issues/year)*
EGS's quarterly bulletin carrying articles on the results of recent research, upcoming meetings, as well as Society's news.

Subscription Rate	Postage Surcharge
included in membership due.	incl.

Nonlinear Processes in Geophysics *(4 issues/ year)*
An interdisciplinary journal published jointly by the EGS and the AGU for the publication of original research involving nonlinear processes in geophysics in the broadest sense. Contributions from both dynamical system theorists as well as geophysicists applying nonlinear methods to fundamental problems in geophysics are welcome.

Subscription Rate			Postage Surcharge
Member	DEM	80,-	Surface mail: DEM 16,-;
Student	DEM	40,-	Airmail (outside
Em. Sc.	DEM	40,-	Europe) DEM 32,-

Physics and Chemistry of the Earth *(thematic issues)*
For the publication of short, self-contained and refereed papers presented at geo- and planetary sciences' conferences.

Subscription Rate			Postage Surcharge
Member	DEM	195,-	incl.
Student	DEM	195,-	incl.
Em. Sc.	DEM	195,-	incl.

Planetary and Space Science *(12 issues/year)*
The key journal for planetary and solar system research, covering cosmochemistry and the origin and evolution of the solar system; small bodies, dust and rings; terrestrial and outer planets and their satellites, including geology, mineralogy, geophysics and dating as well as the formation and dynamics of planetary atmospheres, ionospheres and magnetospheres and their interaction with the solar wind; exobiology and celestial mechanics.

Subscription Rate			Postage Surcharge
Member	DEM	165,-	incl.
Student	DEM	165,-	incl.
Em. Sc.	DEM	165,-	incl.

Surveys in Geophysics *(6 issues/year)*
Up to date summaries of research in all the disciplines covered by the Society. Subscribers are kept informed also of the subjects outside their own specialties.

Subscription Rate			Postage Surcharge
Member	DEM	165,-	incl.
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Em. Sc.	DEM	165,-	incl.

Tectonics *(6 issues/year)*
Includes papers on the deformation of the crust, including mountain building, rifting, seismotectonics, movements of terranes, and plate interactions, as well as contributions in the areas of analytical, synthetic and integrative tectonics.

Subscription Rate			Postage Surcharge
Member	DEM	145,-	Surface mail: DEM 36,-
Student	DEM	75,-	Airfreight: DEM 85,-
Em. Sc.	DEM	75,-	Airmail: DEM150,-

EUROPEAN GEOPHYSICAL SOCIETY
1998 Membership Application & Journal Subscription

Personal Information *(please print all information clearly)*

❒ Prof. ❒ Dr. ❒ Mrs. ❒ Ms. ❒ Mr. ❒ Other _____

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Department/Institute _____

Company/University _____

P.O. Box/Street _____

ZIP Code _____ **City** _____ **Country** _____

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EGS Affiliation *(if you check more than one affiliation, please circle your main interest)*

❒ Solid Earth Geophysics (SE)
❒ Geodesy (G)
❒ Hydrological Sciences (HS)
❒ Oceans & Atmosphere (OA)
❒ Solar-Terrestrial Sciences (ST)
❒ Planetary & Solar System Sciences (PS)

Membership *(students should enclose a copy of their student certificate!)*

Membership is on a calendar year basis. Applications received after 1 October will be made effective as of 1 January of the following year, unless otherwise requested.

❒ Individual Membership: ❒ Regular ❒ Student ❒ Emeritus Scientist
❒ Affiliated Membership* ❒ Corporate Membership**

_____
Name of Aff./Corp. Society

Membership Renewal *(please complete and circle appropriate rates)*

Membership Rates	DEM
Individual Membership	
• **Regular**	55,-
• **Student or Emeritus Scientist**	27,-
• **Life-Time**	1.100,-
Affiliated Membership (*)	37,-
Corporate Membership (**)	paid
Voluntary Donation for:	
• **Young Scientist Travel Award**	
• **Keith Runcorn Travel Award**	
• **East European Support Award**	

Exchange Rates
French Francs
FRF = 3.30 x DEM
Pounds Sterling
GBP = 0.40 x DEM
US Dollars
USD = 0.65 x DEM

* Affiliated Societies: Austrian Society for Meteorology, British Hydrological Society, Canadian Geophysical Union, Challenger Society for Marine Science, Deutsche Meteorologische Gesellschaft, Geophysical Section of the Czech Union of Mathematicians and Physicists, Geophysical Society of Finland, Nordisk Hydrologisk Forening, Royal Astronomical Society, Societé Royale Belge d'Astronomie, de Météorologie et de Physique du Globe, Swiss Specialist Group of Geophysicists

** Corporate Societies: Association of Hungarian Geophysicists, Danish Geophysical Society, Norwegian Geophysical Society, Risø National Laboratory, Swedish Geophysical Society (Membership Fees already paid en bloc by corresponding Society/Institute)

Journal Subscription *(please circle rates and postage surcharges where necessary)*

By accepting journals at members' rates, each member agrees that her/his copy is for personal use only.

No.	Journal Subscription	Rates DEM		Postage Surcharges DEM		
		Members	Students Em. Sc.	Surface	Air Mail	Air Freight
☐	**Annales Geophysicae** (12 issues per year)	150,-	75,-			
☐	**Climate Dynamics** (8 issues per year)	98,-	98,-	34,-	53,-	
☐	**Geophysical Journal International** (12 issues per year)	150,-	55,-			
☐	**Hydrology and Earth System Sciences** (4 issues per year)	140,-	140,-		16,-*	
☐	**Journal of Atmospheric Chemistry** (9 issues per year)	240,-	240,-			
☐	**Journal of Geodynamics** (8 issues per year)	110,-	110,-			
☐	**Nonlinear Processes in Geophysics** (4 issues per year)	80,-	40,-	16,-	32,-*	
☐	**Physics and Chemistry of the Earth** (thematic issues)	195,-	195,-			
☐	**Planetary and Space Science** (12 issues per year)	165,-	165,-			
☐	**Surveys in Geophysics** (6 issues per year)	165,-	165,-			
☐	**Tectonics** (6 issues per year)	145,-	75,-	36,-	150,-	85,-
					* for outside Europe	

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http://www.copernicus.org/EGS/EGS.html

1999 General Assembly
Den Haag, 19 - 23 April

Attend the open EGS Section/IWG Meetings on Wednesay, 22 April, 12.00-14.00, and make your suggestions, to the scientific programme. Further information on the EGS Web Site http://www.copernicus.org/EGS/EGS.html.

European Geophysical Society

Inviting the scientists of the world to participate in the

Millennium Conference on Earth, Planetary & Solar Systems Sciences

- 25th General Assembly -

Fortezza da Basso, Florence, Italy
3-7 April 2000

Joint this unique celebration of the past and the new millennium in the capital of Renaissance and in the beauty of Tuscany.

Suggestions regarding the scientific programme and any inquiries should be addressed to:

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Tel: +49-5556-1440
Fax: +49-5556-4709
EGS@COPERNICUS.ORG
http://www.copernicus.org/EGS/EGS.html

EGS Awards

1. Honorary Membership *(since 1973)*
Honorary Membership is the most prestigious award made by the Society. It is reserved for scientists who have achieved exceptional international standing in geophysics, defined in its widest sense.

2. EGS Badge Award *(since 1988)*
This award is reserved for individuals in recognition of their outstanding service and/or exceptional efforts in the promotion, growth and running of the Society.

3. Young Scientists' Publication Award *(since 1990)*
These awards are made to the younger and more recently established scientists in the geophysical disciplines in recognition of their outstanding contributions to the EGS scientific journals. Each Section may bestow one award each year.

4. Louis Néel Medal *(since 1993)*
This medal has been established by the Section on Solid Earth Geophysics (SE) in recognition of the scientific achievements of Louis Eugène Felix Néel, who shared the 1970 Nobel Prize of Physics for his fundamental research and discoveries concerning antiferromagnetism. This medal is reserved for individuals in recognition of outstanding achievements in the fertilization of the Earth Sciences by the transfer and application of fundamental theory and/or experimental techniques of solid state physics, as defined in its broadest sense.

5. Stephan Mueller Medal *(since 1997)*
This medal has been established in recognition of the scientific and editorial achievements of Stephan Mueller "Founding Father", President, Honorary Members, Badge Awardee and Editor-in-Chief of the European Geophysical Society, for exceptional contributions to *Tectonics and Lithospheric Geophysics*.

6. Beno Gutenberg *(since 1996)*
This medal has been established by the Section on Solid Earth Geophysics (SE) in recognition of the scientific achievements of Beno Gutenberg. It is reserved for individuals in recognition of their outstanding contributions to Solid Earth Geophysics in general.

7. Vening Meinesz Medal *(since 1997)*
This medal has been established in recognition of the scientific achievements of Vening Meinesz. It is reserved for distinguished research in geodesy in general.

8. John Dalton Medal *(since 1997)*
This medal as been established by the Section on Hydrological Sciences (HS) in recognition of the scientific achievements of John Dalton. It will be awarded by the European Geophysical Society for distinguished research in Hydrology viewed as an Earth science.

9. Fridtjof Nansen *(since 1996)*
This medal has been established by the Section on Oceans and Atmosphere (OA) in recognition of the scientific achievements of Fridtjof Nansen. It will be awarded by the European Geophysical Society for distinguished research in Oceanography.

10. Vilhelm Bjerknes Medal *(since 1995)*
This medal has been established in 1995 by the Section on Oceans and Atmosphere (OA) in recognition of the scientific achievements of Vilhelm Bjerknes. It is reserved for distinguished research in atmospheric sciences.

11. Milutin Milankovitch Medal *(since 1993)*

This medal has been established by the Section on Oceans & Atmosphere (OA) in recognition of the scientific and editorial achievements of Milutin Milankovitch. This medal is reserved for scientists for their outstanding achievements in climatological sciences.

12. Julius Bartels Medal *(since 1996)*
This medal has been established by the Section on Solar-Terrestrial Sciences (ST) in recognition of the scientific achievement of Julius Bartels. It is reserved for outstanding research in solar-terrestrial sciences.

13. David Robert Bates Medal *(since 1992)*
This medal has been established by the Section on Planetary & Solar System Sciences (PS) in recognition of the scientific and editorial achievements of Sir David Robert Bates FRS. It is reserved for scientists for their exceptional contributions to planetary and solar system sciences.

14. Hannes Alfvén Medal *(since 1997)*
This medal has been established by the Section on Solar Terrestrial Sciences (ST) and Planetary Sciences (PS) in recognition of the scientific achievements of Hannes Alfvén, to be awarded for outstanding scientific contributions towards the understanding of plasma processes in the solar system and other cosmical plasma environments.

15. Sergey Soloviev Medal *(since 1996)*
This medal has been established by the Interdisciplinary Working Group (IWG) on Natural Hazards (NH) in recognition of the scientific achievement of Sergey Soloviev. It is reserved for scientists for their exceptional contributions to natural hazards, in particular, for their research aiming at an improvement of our knowledge of basic principles as well as for the assessment and proper mitigation of hazards in view of environmental protection and the integrity of human life and socio-economic systems.

16. Young Scientists' Travel Award *(since 1977)*
These awards are intended to help young European scientists or young scientists working in Europe to attend the scientific conferences of the Society by providing a financial contribution to the cost of travel of max. 500 Swiss France & free registration.

17. Keith Runcorn Travel Award *(since 1997)*
These awards are intended to assist a limited number of young American scientists to attend the General Assemblies of the Society by providing a financial support to their travel expenditures of max. 500 US$ & free registration.

18. East European Support Award *(since 1989)*
These awards are intended to help scientists from the countries in East-Europe to attend the scientific conferences of the Society by covering health insurance, local travel costs, conference fees, accommodation costs, and some modest amount for daily expenses.

Young Scientists' Publication Award

Since 1990 the Society has sponsored the Young Scientists' Publication Award scheme for all of its official journals. If you are less than 35 years old and if your paper, of which you are the principal author, has been published or accepted for publication in one of the official journals of the EGS by 1 December, you are eligible to be considered for an award. The award consists of a fine commemorative medal and the equivalent of a Young Scientists' Travel Award, i.e. free registration and max. 500 SFR to assist your travel to the next General Assembly of the Society. The award are made during the Opening Ceremony of the Assembly. All entries will be judged by special committees convened by the appropriate Section Vice-Presidents of the Society. Only one award per Section will be made each year.

Please send your entry to the EGS Office not later than 1 December.

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